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Surficial geology of the Calgary urban area

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Abstract

This study presents the results of mapping of the surficial material in an area of approximately 2985 km² with the city of Calgary at its center. The mapping was conducted to determine the distribution and stratigraphic relationships of the surficial materials. Such information provides an important data base on resources, construction conditions, and potential geologic hazards and as such will assist in planning of development as well as in the early design stages of specific projects in the Calgary urban area.

The area extends from the foothills in the southwest to the plains in the east. The eroded bedrock surface, with local relief of as much as 200 m, is draped by surficial deposits that range in thickness from less than a metre to more than 85 m. Underlying the plains in the east, the bedrock consists of flat lying to gently dipping sandstone, siltstone, and shale of the Porcupine Hills Formation of Cretaceous or Paleocene age. In the foothills zone in the western part of the area, steeply dipping folded and faulted Cretaceous marine shale alternates with marine marginal and continental sandstone and siltstone beneath the north-northwest trending valleys and foothill ridges respectively.

The surficial materials, which were mapped to a depth of 6 m, consist dominantly of loamy to clayey glacial till and clayey to silty glacial lake sediment. Six distinct stratigraphic units have been mapped within the glacial till sequence. The various stratigraphic units within the till sequence are differentiated by both field-recognizable and laboratory determined compositional differences including pebble composition, grain-size, carbonate mineral content, clay mineral composition, and petrology of the very coarse sand.

The gravel deposits throughout the area constitute the most significant economic resource within the surficial materials. Extensive deposits of gravel of Tertiary age cap the Broadcast and Big Hill-Nose Hill uplands beneath a till cover. Other major gravel deposits include as much as 10 m of early Pleistocene gravel covering the floor of the preglacial Bow River valley, and the late Wisconsinan valley floor deposits along the Bow and Elbow Rivers and their major tributaries. This resource has been rapidly consumed or been made unavailable for development by the rapid expansion of the City of Calgary during the past two decades.

No significant geologic hazards are present in the Calgary area, although slope failures are not uncommon on steep slopes, especially along the Bow River valley. Although failures have occurred in nearly all geologic settings, the most common setting is in thick lacustrine sediment, especially where saturated permeable beds occur in the succession. The silt and very fine sand that make up much of the lacustrine sequence through the city are susceptible to rapid and severe gully erosion where exposed on even gently unvegetated slopes. The presence of quartzite gravel or very hard sandstone bedrock beneath a thin cover of till or lake sediment in many parts of the area results in difficult digging conditions that can significantly increase construction costs.

The surficial materials in the Calgary area are the products of erosional and depositional activities of rivers, lakes and glaciers acting over a period of several tens of millions of years. During the middle and late Tertiary, rivers flowing out of the mountains eroded the early Tertiary and Cretaceous bedrock, leaving remnants of their gravel-covered valley floors on the major uplands in the area. Erosion continued into the early Pleistocene with the ancestral Bow River cutting its valley nearly to the level of the present valley floor. The gravel deposits of this river are buried beneath the earliest glacial sediment recognized in the area, the weathered pre-Spy Hill till. This till was deposited by a pre-late Wisconsinan glacier that advanced from the mountains to the west. Some time around 25 000 years before present, the late Wisconsinan glaciation began with the advance from the mountains of the Bow Valley glacier, which deposited till of the extensive lower unit of the Spy Hill Formation nearly to the eastern edge of the study area. Before this glacier had completely melted from the area, it was overridden by the continental glacier advancing from the north and northeast. This glacier deposited till of the upper unit of the Spy Hill Formation as far west as Priddis and Cochrane, and the lower part of the Lochend Formation in the eastern part of the area. A series of lakes formed where rivers from the mountains and meltwater from the glacier were dammed by the ice. As the ice margin wasted back toward the east exposing progressively lower outlets, the lakes dropped and the Bow and Elbow rivers cut their valleys nearly to their present levels, depositing and then re-eroding gravel at each level. There is evidence of at least one minor readvance of the glacier margin during this period of retreat. The continental glacier wasted completely out of the study area for an unknown period of time, perhaps several thousand years, before readvancing to deposit the till of the Balzac and Crossfield Formations in the eastern and northeastern parts of the area. The same pattern of lakes in the major ice-dammed valleys, with successively lower levels controlled by the wasting glacier, characterized the final deglaciation of the Calgary area. The Bow River and its tributaries were cut to their present levels while glacier ice still persisted in, or just to the northeast, of the area. The period since deglaciation, which began perhaps as much as 13 000 years before present, has been characterized by reworking of the river gravels, deposition of extensive alluvial fans over the gravel along the sides of the valleys through the area, and deposition of as much as 1 m of windblown silt or loess on the uplands east of the Bow River south of the city.

Introduction

This report presents the findings of a study of the geology of the Calgary urban area that was conducted by the Alberta Research Council between 1974 and 1982. The study area includes the Calgary (82O-1) and Priddis (82J-16) 1:50 000 NTS map sheets as well as the west half of the Dalroy (82P-4) and Dalmead (82I-13) sheets (figure 1). Four maps depicting the distribution of surface materials in these map sheets have been published at a scale of 1:50 000 by the Alberta Research Council (Moran, 1986a, 1986b, 1986c, 1986d). The present report is a companion to these maps. Between the completion of these maps and the present report, re-evaluation of petrologic and stratigraphic data has resulted in shifts in the location of several boundaries of till sheets. These changes do not alter the validity of the interpretation in the maps of surficial material.

Fieldwork on the project began in 1974 under the direction of Robert Nowack, a graduate student in the Department of Geology at the University of Alberta. This initial study was focused on a smaller area in the center of the present study area. The project area was expanded to its present size under the direction of Ron May and Bob Young. Management of the project

passed to Stephen Moran in 1977. Fieldwork was completed during 1978.

The present report focuses mainly on the stratigraphic geology of the unconsolidated sediment overlying the Cretaceous bedrock. The bedrock consists of hard sandstone, siltstone and shale of the Porcupine Hills Formation in the eastern and central parts of the study area and Wapiabi and Brazeau Formations in the west. It was not possible to penetrate these rocks with the solid stem auger used to drill most of the testholes in the study area (figure 1, in pocket) and, therefore, the top of bedrock has been considered as the base of exploration for this study.

This report is organized into three major sections. The first consists of descriptions of the six stratigraphic units recognized in the late Tertiary and Quaternary sequence within the study area. The second major section is a discussion of the geology of the area. The area has been subdivided into 13 districts, which are essentially physiographic units, on the basis of geology and morphology (figure 1). The discussion of each district is divided into four sections: description, characteristics of stratigraphic units, resource potential, and factors influencing land use. The third section of this report is a review of the Quaternary history of the Calgary area.

For a detailed description of the surficial geology, the reader is referred to the maps of surface materials (Moran, 1986a, 1986b, 1986c, 1986d). A further important source of detailed information on the distribution and characteristics of surface materials is the *Soil Survey of the Calgary Urban Perimeter* by MacMillan (in press).

Stratigraphy

Tertiary gravel and Empress Formation

A layer of Tertiary gravel caps the major uplands in the Calgary area (figure 2, in pocket). This gravel is overlain everywhere by till and is exposed only in outcrops at various places along the edges of the major uplands and in gravel pits. These high-level gravel deposits cap both the Broadcast Hill and Big Hill-Cochrane uplands where two separate surfaces have been recognized (Shetsen, 1981, p. 16). At least two lower gravel-floored surfaces have been recognized in the subsurface along the north side of the Bow River valley northwest of Calgary (figure 3, cross section D-D′, in pocket). The floor of the ancestral valley of the Bow River also consists of gravel and, here too, more than one surface has been recognized on the basis of borehole data southeast of Calgary near the eastern edge of the study area (figure 4, cross section Q-Q′, in pocket). The gravel underlying the two lowest surfaces is correlated with the Empress Formation (Whitaker and Christiansen, 1972).

Although it is likely that at least the lowest deposits in the valley of the ancestral Bow River valley are early Pleistocene in age, no paleontological evidence is available to assign a definite age to any of these deposits. The sequence of gravel-floored surfaces between the floor of the ancestral Bow River and the upland surfaces makes any attempt at placement of the boundary between the Tertiary and Quaternary a guess at best.

The Tertiary gravel and Empress Formation consist of well-rounded pebbles and cobbles of quartzite, dark gray limestone, and minor amounts of local sedimentary rock. Percussion marks are abundant on many of the larger cobbles. Granitic and gneissic rocks are totally absent. In some outcrops, the gravel has been partly or completely cemented by calcium carbonate to form conglomerate, as in a road-cut on the north edge of the Bow River valley in 5-25-25-3W5. In other places, the porosity of the gravel is filled with a yellowish orange to salmon buff silt. This silt is commonly in boreholes in the northwestern part of the Big Hill-Cochrane upland and in road-cuts north of Cochrane, just north of the study area.

There have been reports of till underlying some of the gravel on the Big Hill-Cochrane upland (Rutter and Wyder, 1969; Nowack, 1981). However, the tricone bit generally used to penetrate the hard gravel makes it difficult to obtain good samples of the underlying material. During a program of rotary drilling in 1977 examining the deeper parts of the fill in the ancestral valley of the Bow River in the southeastern part of the study area, the driller logged till beneath the basal gravel in two or three holes. Closer evaluation of the samples indicated that they were a mixture of fragmented gravel and oxidized bedrock, rather than till.

Pre-Spy Hill till

The oldest sediment of glacial origin that has been recognized in the Calgary area is a discontinuous unit of hard stony till. This unit is present in scattered locations at the base of the fill of the ancestral Bow River valley southeast of the city of Calgary and in places on the Big Hill upland northwest of the city. The stones in this till include an abundance of pink and purple quartzite and other rock types characteristic of a source in the mountains. The crystalline to carbonate ratio of the very coarse sand fraction is very low. This lowermost till has been recognized in five testholes and sections in the lower Bow valley district where it ranges in thickness from 3.0 m to 16.5 m. This till is a clayey silt (24 percent sand - 39 percent silt - 37 percent clay) and contains abundant carbonate both in the matrix (48 mL CO_2/g) and in the coarse sand fraction. The ratio of crystalline to carbonate grains in the very coarse sand is low (0.10) as is the ratio of smectite to kaolinite plus chlorite (0.45). This till was also encountered in two holes on the southwest edge of the Big Hill upland. Here, the oxidized till has a texture of 18-40-42. The

matrix carbonate content is 74 mL/g and the smectite to kaolinite plus chlorite ratio is 0.66.

Spy Hill Formation

The oldest widespread stratigraphic unit of Quaternary age in the Calgary area is the Spy Hill Formation (figure 5, in pocket). It is the surface unit or subcrops beneath lacustrine sediment over the western half of the study area. Nearly everywhere the unit consists of till, but in places, as in the upper Bow valley district, lacustrine clay interbedded with till is included.

The Spy Hill Formation was defined by Tharin (1960, pp. 62-65) from a series of outcrops on the Big Hill upland, northwest of Calgary. The type section, is located in NE29-25-2W5, (table 1).

Tharin (1960, p. 63) described the till of the Spy Hill Formation as "calcareous, buff to reddish grey, moderately to highly pebbly, sandy-silty till. It contains pebbles of rounded quartzose sandstone, polished and striated dark gray carbonate, angular sandstone, and an occasional coal fragment. The clay mineral fraction contains 20.6% montmorillonite, 61.7% illite, 11.7% chlorite and 6.0% kaolinite." He reported the carbonate content as 28 percent.

As a result of the present study, two distinctive till units have been recognized within the Spy Hill Formation on the basis of grain size, mineralogy and stratigraphic position.

Table 1. Type section of the Spy Hill Formation (Tharin, 1960, p.62)

Unit		Thickness feet	Thickness metres
A	Soil, gray, leached 8 inches, very pebbly.	0.67	0.20
	Spy Hill till		
B	Till, calcareous, reddish brown (fresh) buff (dry), silty, pebbly; forms cliffs. Pebbles striated and polished, dark gray carbonates, quartzose sandstone, Paskapoo sandstone and minor shale. Base unexposed.	6.0	1.83

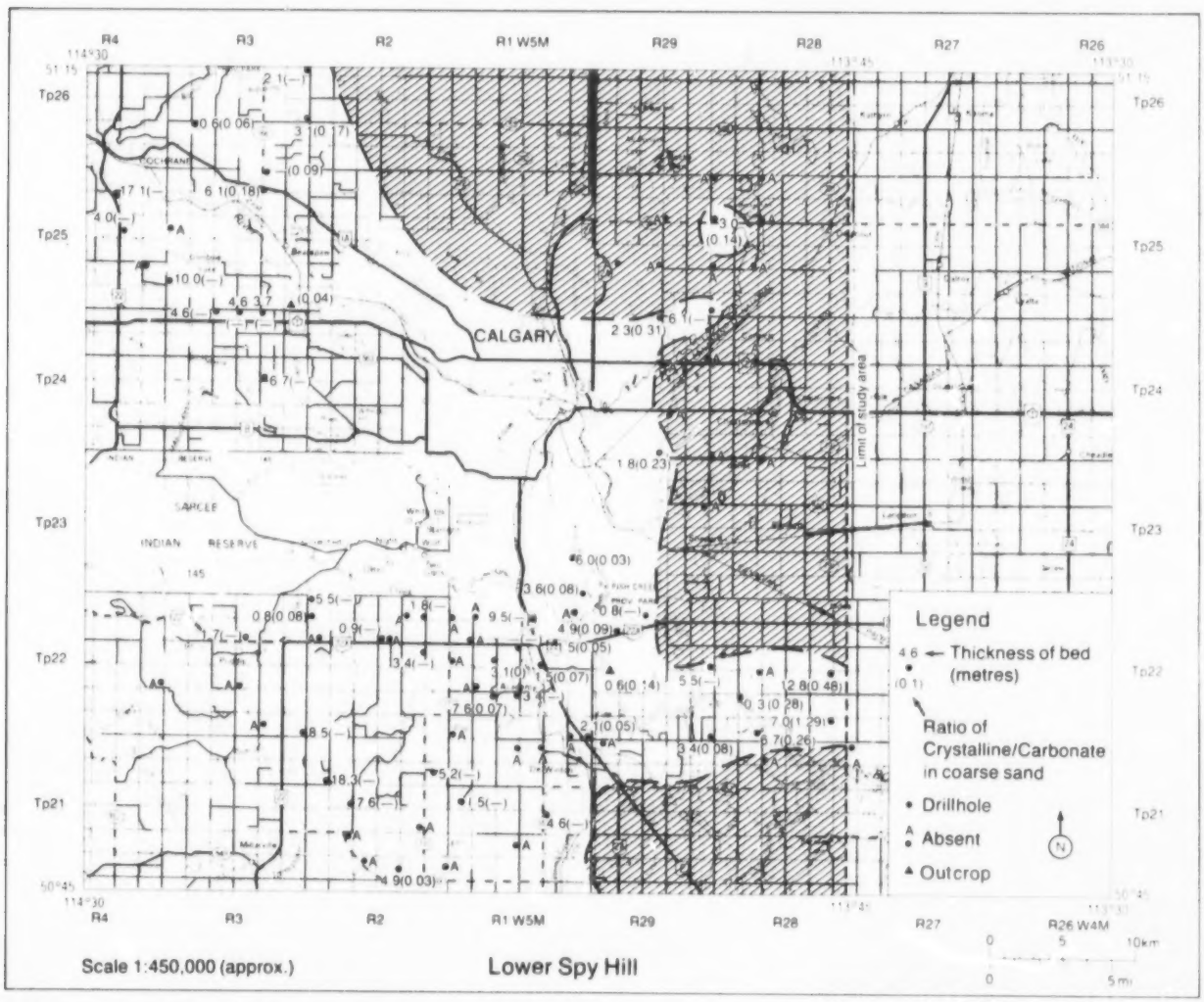


Figure 6. Distribution of the lower unit of the Spy Hill Formation

Lower unit

The lower unit is the surface till in the extreme western part of the study area and underlies either the upper unit or the overlying Lochend Formation throughout the remainder of the study area (figures 5 and 6). The lower unit consists of till that is generally hard, dark gray, and contains abundant stones, dominantly dark carbonate and pink and purple quartzites. Granitic pebbles are extremely rare or absent. The matrix texture is variable, but generally consists of 15 to 25 percent sand, 30 to 40 percent silt, and 30 to 50 percent clay. Within any given district the compositional range is narrower than in the whole area and the relative difference from the overlying units is consistent. The carbonate content of this till is generally the highest of all the till units in the eastern part of the Calgary area. Along the Bow valley, the carbonate content ranges from 43 to 60 mL/g. In the southwestern part of the area, incorporation of large amounts of noncalcareous bedrock results in lower values ranging from 17 to 36 mL/g. The clay mineral suite is generally characterized by lower montmorillonite content than the other units, with montmorillonite to kaolinite plus chlorite ratios ranging from 0.28 to 0.58. The crystalline to carbonate ratio in the very coarse sand fraction is also the lowest of all the units in the Calgary area, generally being less than 0.10 and commonly less than 0.05. Only in the extreme eastern part of the area are higher values found. Here, values as great as 0.34 and 0.23 are found in the lower Bow valley and Shepard-Delacour districts respectively.

The abundance of pink and purple quartzite pebbles and dark gray and black carbonate grains, as well as the very small number of grains derived from the Canadian Shield, indicate that the lower unit of the Spy Hill Formation was deposited by a glacier that advanced

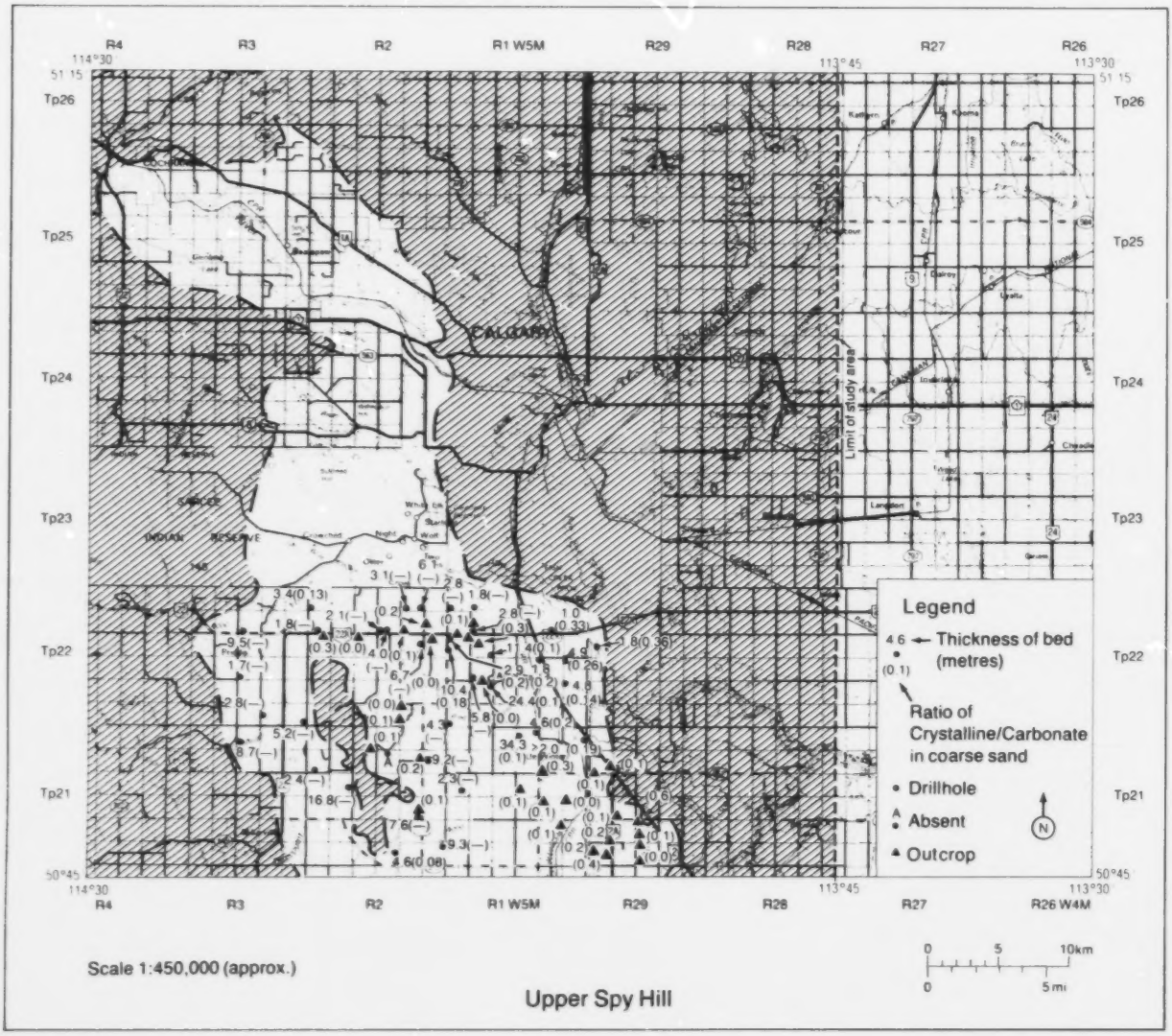


Figure 7. Distribution of the upper unit of the Spy Hill Formation

eastward out of the mountains by way of the Bow River valley.

Upper unit

The upper unit of the Spy Hill Formation is the surface till unit or subcrops beneath lacustrine sediment in the west-central part of the Calgary area (figures 5 and 7). It lies between the outcrop areas of the lower unit to the west and the Lochend Formation to the east. The upper unit of the Spy Hill Formation consists of till that is very similar in appearance to the lower unit. It is generally dark gray to olive brown where oxidized, and is somewhat less stony and sandy, and more clayey than the lower unit. Like the lower unit, dark pebbles and cobbles of carbonate rocks and pink and purple quartzites are abundant; unlike the lower unit, granitic pebbles are common. The carbonate content of the matrix is somewhat higher than in the lower unit, with values ranging from 38 to 59 mL/g. The crystalline to carbonate ratio of the very coarse sand fraction generally ranges from 0.10 to 0.35. The ratio of montmorillonite to kaolinite plus chlorite, ranging from 0.40 to 0.82, is higher than for the lower unit. The compositional differences between the two units of the Spy Hill Formation are well summarized by data from a section along the south side of the Bow River valley west of Bowness in LSD 4-5-25-2W5 (figure 8) and testhole Cal 78-2 on the Big Hill upland between Calgary and Cochrane in NW4-35-25-3W5 (figure 9).

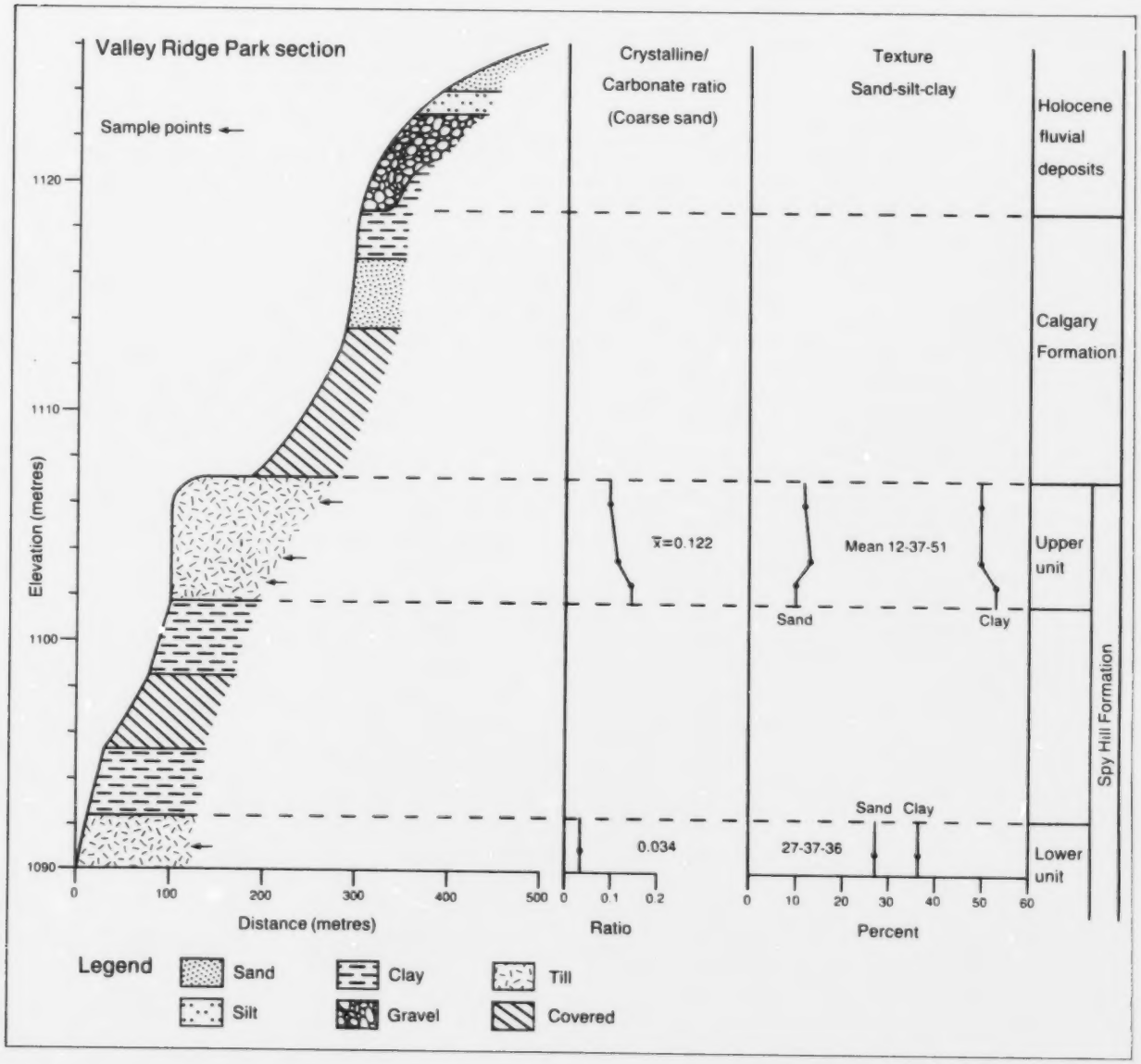


Figure 8. The Valley Ridge Park section (4-5-25-2W5) in the upper Bow valley district, showing upper and lower units of the Spy Hill Formation overlain by the Calgary Formation

The upper unit of the Spy Hill Formation is recognized beneath the Lochend Formation in only a small number of testholes in a very narrow zone along the Bow River valley south of Midnapore. East of this area, till of the lower unit of the Spy Hill Formation has a composition that is indistinguishable from the Lochend Formation.

On the basis of compositional parameters that differ from the lower unit, largely in the increased crystalline content in the coarse sand fraction, the upper unit of the Spy Hill Formation is interpreted to have been deposited by a glacier that advanced into the Calgary area from the northeast. The composition of this till sheet was apparently so altered by incorporation of debris from the underlying, lower unit of the Spy Hill Formation and fluvial sediment derived from it, that the upper unit more closely resembles the lower unit than the Lochend Formation.

Lochend Formation

The Lochend Formation consists of till and stratified drift that overlies the Spy Hill Formation in the central and eastern part of the Calgary area. The formation crops out in a narrow belt that extends roughly north-

Table 2. Type section of the Lochend Formation (Tharin, 1960, pp.55-65)

Unit		Thickness feet	Thickness metres
A	Soil, recently disturbed by bulldozer	0.83	0.25
	Crossfield till		
B	Till, calcareous, brown, sandy-silty moderately pebbly, laminar structure, pebbles mostly local; few granite and gneiss pebbles.	7.0	2.13
	Lochend stratified drift		
C	Sand, calcareous, light tan, silty, fine-grained. 1 to 2 inch beds of silt. Crossbedded in part. Passes horizontally into a contorted zone of bedded silts, sands and clays.	8.0	2.44
	Lochend till		
D	Till, calcareous, brown (10YR 5/3) clayey, slightly to moderately pebbly. Dense and massive. Pebbles mostly local and western but granite and gneiss pebbles occur. Base unexposed.	5.0	1.52

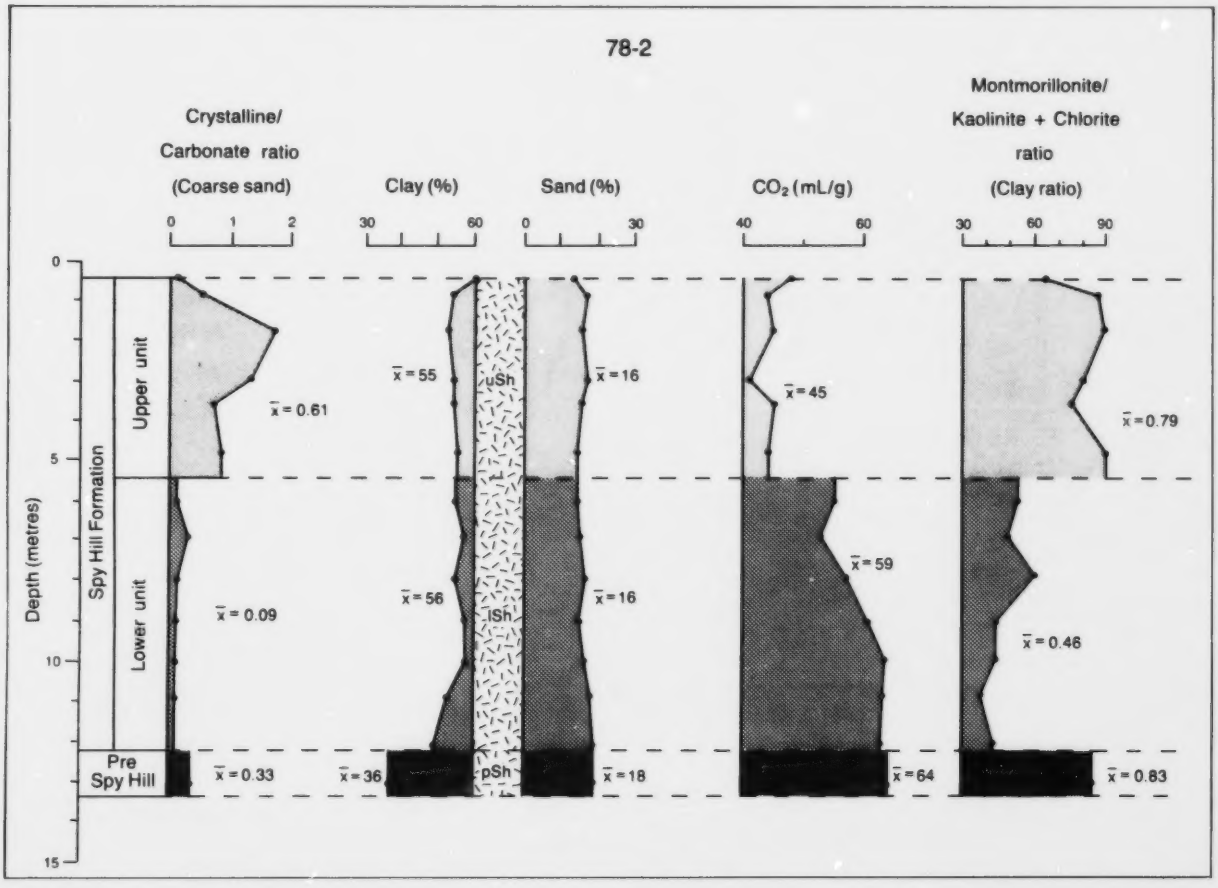


Figure 9. Composition of upper and lower units of the Spy Hill Formation and the pre-Spy Hill till at testhole Cal78-2 (NW4-35-25-3W5)

northwest to south-southeast across the center of the study area (figures 5 and 10).

The Lochend Formation was defined by Tharin (1960, pp. 65-67). The type section is located in a gully cut into the east valley side of Nose Creek in the center of 2-25-1W5, just on the west edge of Calgary International Airport, at the end of runway 07-25 (table 2).

The till of the Lochend Formation commonly contains dark gray limestone and dolomite pebbles from the Rocky Mountains as well as granitic and gneissic pebbles. Tharin (1960, p.67) indicated that it contained the most montmorillonite (49 percent) and the least illite (37 percent) of all the tills in the Calgary area and that the till contained about 18 percent matrix carbonate.

Re-examination of the type section of the Lochend Formation in 1977 and study of a manmade excavation just across the road to the west in 1981, leads the author to conclude that, on the basis of mineralogical composition, the upper till in this area is the Balzac Formation rather than the Crossfield Formation as concluded by Tharin (1960).

On the basis of data collected as part of the present study, the till of the Lochend Formation is generally silty, but with a slightly higher sand content than either the upper unit of the Spy Hill Formation or the Balzac Formation. The crystalline to carbonate ratio of the 1 to 2 mm sand fraction is higher in the Lochend Formation than in either the Spy Hill or Balzac Formations, but lower than in the Crossfield Formation. Details of these and other compositional parameters are described below in the discussions of various districts within the area.

The boundaries of the Lochend Formation mapped in this report to the south and east of Calgary (figures 5 and 10) differ from those mapped earlier by Moran and

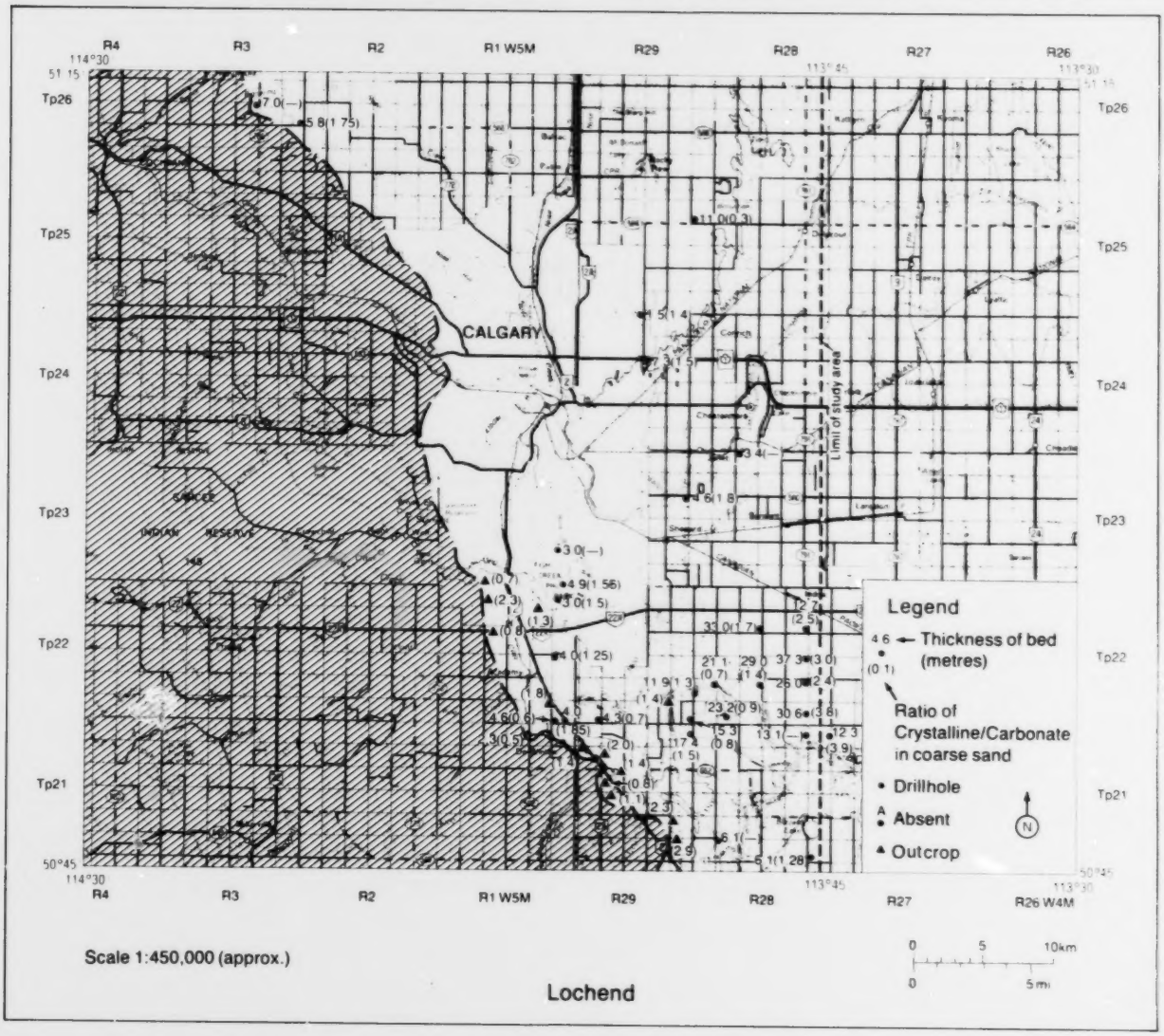


Figure 10. Distribution of the Lochend Formation

Clayton (1983) as a result of re-evaluation of petrologic data.

The Lochend Formation was deposited by a glacier that advanced into the area from the northeast. On the basis of pebble content and composition of the very coarse sand fraction, it appears that this glacier contained elements of continental ice derived from the northeast and mountain glaciers flowing out of valleys to the north.

Balzac Formation

The Balzac Formation overlies the Lochend Formation in approximately the eastern half of the study area (figures 5 and 11). It crops out in an irregular shaped belt that ranges in width from 1.5 to 25 km through the north-central part of the area (figure 5). The formation consists largely of till, but along the valley of Nose Creek, silty lacustrine sediment that underlies the till is included in the Balzac Formation. South of Calgary, the boundary of the Balzac Formation as mapped in this study differs from that published earlier by Moran (1986a, 1986b) as a result of reinterpretation of petrologic data.

The Balzac Formation was named by Tharin (1960, pp. 70-72) from an exposure in the valley side of the Bow River just north of Riverside Boulevard at St. George Island in the city of Calgary (9-14-24-1W5) (table 3). The area containing the type section has since been extensively disturbed by construction for the Calgary Zoo, and the location and even existence of the original section is in doubt. Till of the Balzac Formation is silty everywhere and generally contains few stones. The stones are dominantly locally derived sandstone and siltstone, but dark carbonate and quartzite pebbles are abundant. The general absence of pink and purple quartzite pebbles and the scarcity of granitic and gneissic pebbles are also characteristic.

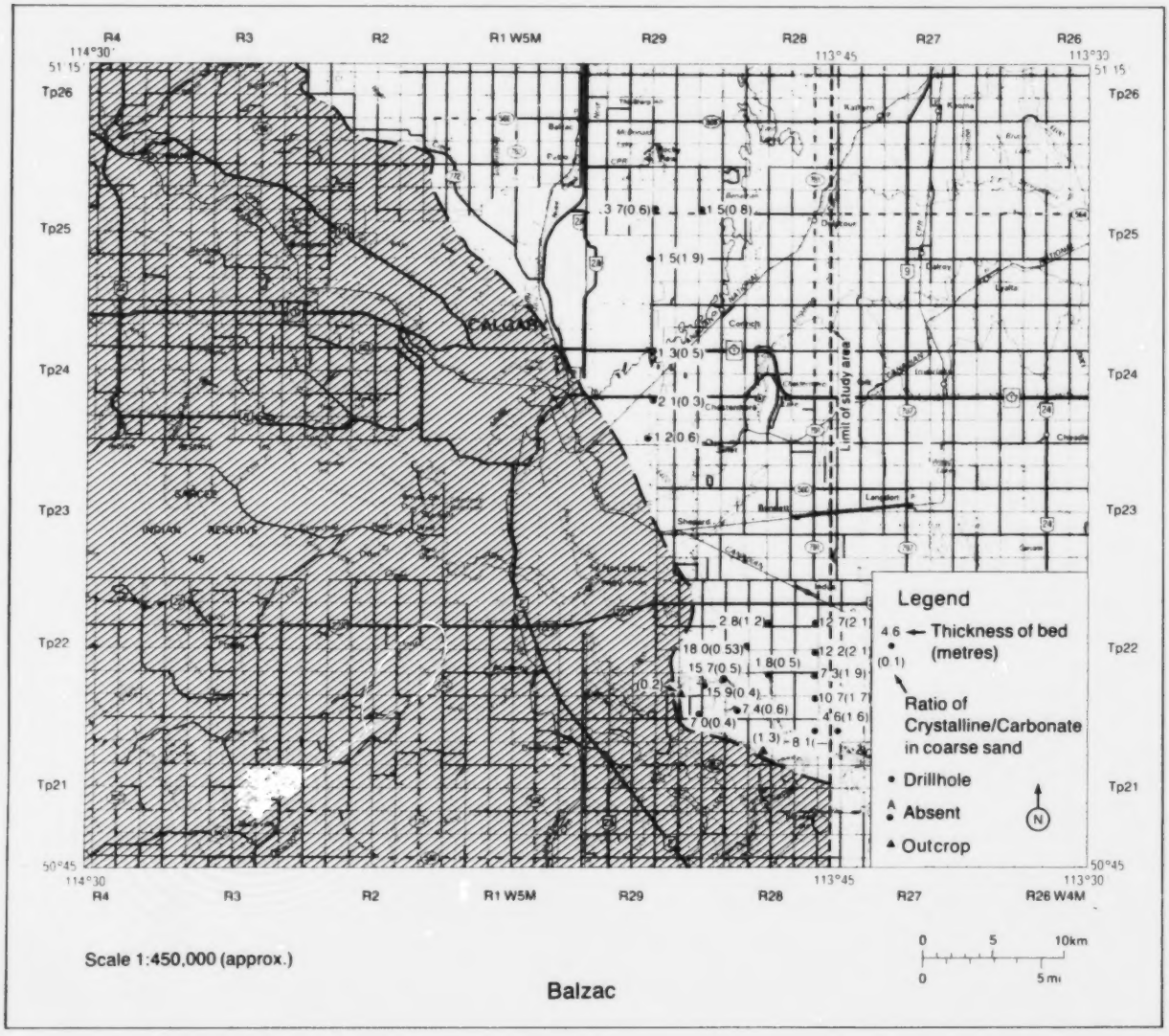


Figure 11. Distribution of the Balzac Formation

Carbonate content of the matrix is generally higher than in either the Lochend or overlying Crossfield Formations, but lower than in the Spy Hill Formation. The crystalline to carbonate ratio in the very coarse sand fraction is lower than in any unit except the Spy Hill Formation.

On the basis of a conspicuous, morphologically defined ice margin, two subdivisions of the Balzac Formation were recognized by Proudfoot et al. (1981, pp.228-229) and Moran (1986c). These subdivisions have not been recognized on a lithologic basis nor have they been recognized in section or borehole. Therefore, no stratigraphic subdivision of the formation is defined.

On the basis of till composition and morphologic flow direction indications from fluted terrain and washbound moraine, it is evident that the Balzac Formation was deposited by a glacier that advanced into the Calgary area from the north-northeast. The ice was derived from glaciers flowing out of the mountains north of the Calgary area.

Crossfield Formation

The youngest stratigraphic unit in the Calgary area that contains till is the Crossfield Formation, which is the surface unit in most of the eastern third of the area (figures 5 and 12).

The Crossfield Formation was named by Tharin (1960, pp. 72-73), who designated the gully exposure on the western edge of the Calgary International Airport in center of 2-25-1W5 as the type section (table 2). In this section, an upper till unit 2 m thick was defined as the type Crossfield. As was mentioned above in discussing the Lochend Formation, for which this section was also designated as the type, the upper till at this site is most certainly the same till as the type Balzac Formation. This poses an interesting dilemma

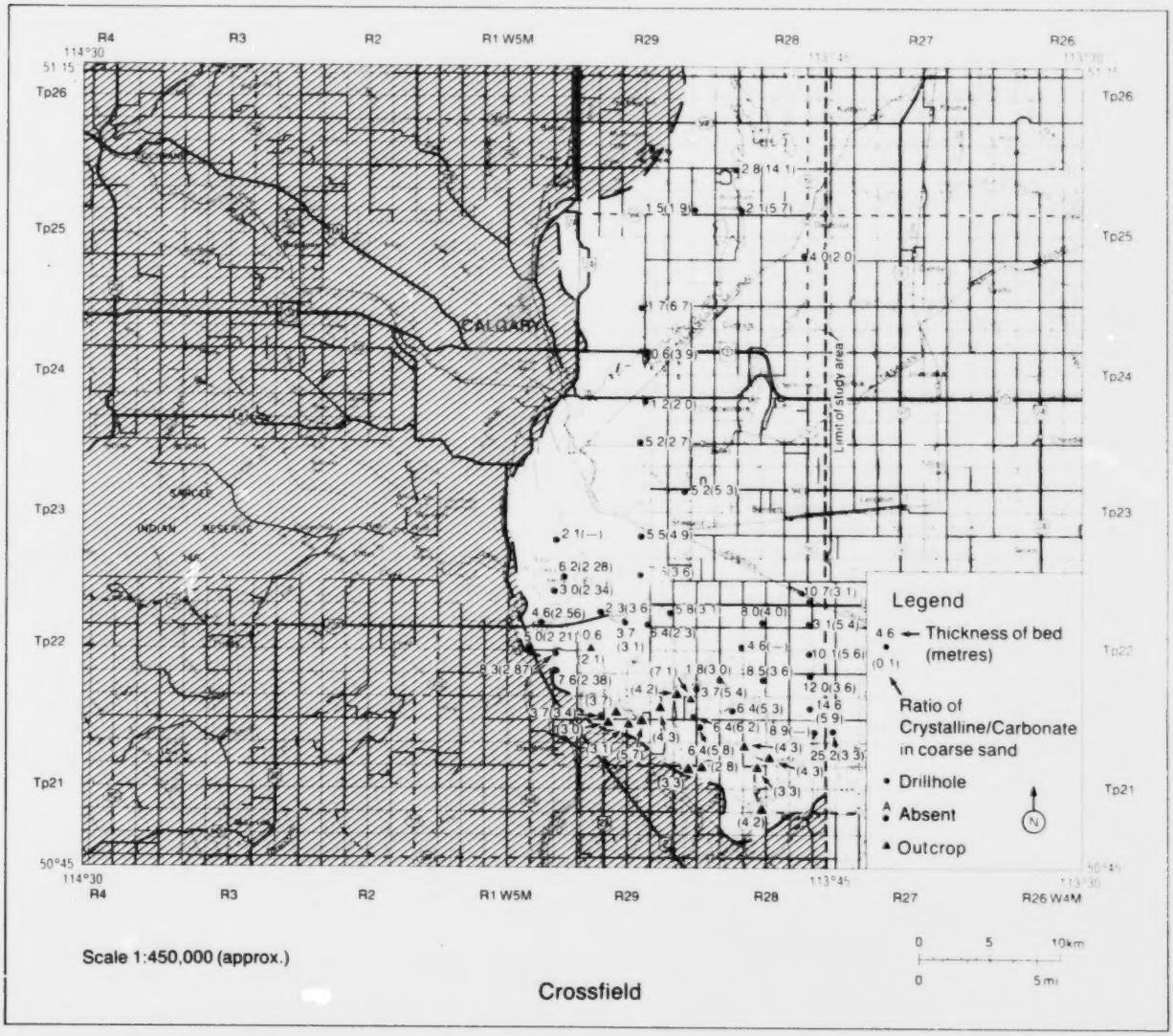


Figure 12. Distribution of the Crossfield Formation

Table 3. Type section of the Balzac Formation (Tharin, 1960, pp.70-72)

Unit		Thickness feet	Thickness metres
A	A and B soil zones, sandy, columnar structure, highly calcareous.	1.67	0.51
	Balzac till		
B	Till, light brown, calcareous, very sandy, slightly pebbly, coaly, massive, blocky. Contains some thin clay lenses. Pebbles mostly western, but 3 Shield pebbles found. 17A/10A = 1.81; CO_3% = 16.5.	30.67	9.35
	Lochend stratified drift		
C	Sand and clay, calcareous, light brown interbedded (rhythmites). Base and top contorted. Contains a few pebbles, and many small coal fragments. Top truncated. 17A/10A = 1.46; CO_3% = 21.	12.00	3.66
	Spy Hill till		
D	Till, light brown, calcareous, sandy, slightly pebbly, coaly, massive: pebble-cobble zone at top.	1.00	0.30
E	Sand and silt, calcareous, light brown, bedded, several very clean sand lenses.	0.67	0.20
F	Till, calcareous, olive brown, sandy, moderately pebbly, very dense, coaly; pebbles western but may in large part be derived from underlying gravels.	2.00	0.61
	Saskatchewan sands and gravels		
G	Gravel, calcareous, light gray, poorly sorted, clayey to sandy lenses; no Shield pebbles present. Contact with overlying till is transitional. There is generally a zone of coarse gravel at top of unit.	8.00	2.44
	Paskapoo Formation		
H	Sandstone		

Table 4. Type section of the Crossfield Formation, DeWinton Section (7-5-22-28W4)
Sector description is a composite of the outcrop and Borehole Cal 77-8. Part of description taken from Stalker 1963 (pp. 48-50).

Stratigraphic Unit	Unit Thickness (m)	Unit Description and Comments	Probable Genesis	Mean Matrix Texture % Sand (standard deviation)	% Silt	% Clay	Matrix Carbonate Content mL CO_2/g [% CO_3]	Coarse Sand Crystalline / Carbonate
Calgary Formation	0.6	silt-silty fine sand; light to dark brown, occasional small pebbles, soil developed on upper surface; paleosol at 0.25 m; sharp low contact	aeolian					
	2.9	silt-silty fine sand - fine sand; light to dark brown; occasional small pebbles, sandier towards base, sand is cross-bedded, with local pebble concentrations along top, soil developed on top of this unit, sharp low contact	fluvial					
Crossfield Formation	6.4	pebble-loam; olive to dark olive (2.5y -3/3 -3/4m) silty-clayey; poorly consolidated near top, contains silt lenses; lower contact sharp (8 samples)	till	30 (1.7)	34	36 (1.8)	23.2 [9.8]	5.3
	3.7	silty clay; light brown; stony; indurated discontinuous; lower 0.8 m is fine to medium sand, with no stones, lower contact sharp; probably represents fluvially eroded remnant to pebble-loam found at same stratigraphic level in borehole behind section (3 samples)	till? / till*	19 (1.0)	44	37 (0.6)	43.8 [19.0]	0.8 highly variable
Balzac Formation	2.7	silty sand-sand-silt; pale olive-olive (5y-6/3.5-4.5/4m); few pebbles, laminated; sharp lower contact	lacustrine					

	4.0	pebble-loam; sandy-silty, gray (5y-5m); compact; consists of alternating dark gray clayey compact diamicton and fine stoneless sand, Diamicton beds range up to 1.2 m and sand up to 1.0 m thick; sharp lower contact (3 samples)	till?	40 (1.5)	40	21 (2.1)	50.4 [21.5]	0.45
	3.4	sand and gravel; sandy; well sorted; stones up to 10 cm in diameter, grades from gravel at the top to sand at base; diamicton occurs sporadically below upper gravelly portion of the unit, sharp lower contact	glacio-fluvial					
	4.9 *	pebble-loam; silty-sandy; very dark (5y-4/1m) very stony; compact, silt bed or lens along lower contact (5 samples)	till	35 (5.8)	41	24 (3.5)	42.2 [18.0]	0.76
Lochend Formation	2.7	pebble-loam; silty-clayey; very dark gray, (5y-4/1); stony; compact, sharp lower contact (3 samples)	till	24 (2.0)	40	36 (3.1)	35.0 [14.8]	0.65
	3.4	pebble-loam; silty; dark gray (5y-3/1m) very few large stones, small stones common; compact (3 samples)	till	33 (2.5)	35	32	35.7 [15.1]	1.16
	12.2 *	pebble-loam; silty-clayey; dark gray to very dark gray; (5y-3/1-4/1m); stony, compact (13 samples)	till	22 (1.7)	37	41 (1.3)	37.3 [15.7]	0.90
Lower Unit Spy Hill Formation	6.7 *	pebble-loam; silty-clayey; olive gray (5y-4/2); more stones than above till; compact (7 samples)	till	22 (1.7)	37	41 (1.3)	37.3 [15.7]	0.90
Empress Formation	1.0	sand and gravel; slight fining upward from coarse sandy gravel. Angular blocks of local bedrock common near base. Quartzite, sandstone, dolomite an limestone are common.	fluvial					

*intersected in auger hole but little or no trace found in outcrop

for which there is no simple solution. Following the principles of stratigraphic nomenclature to the letter would require renaming the unit presently mapped as "Crossfield" and designating a new type section. Most likely, the best solution would be to drop the name Crossfield Formation altogether. Alternatively, the destruction of the type section of the Balzac Formation leads to the possibility of using the name Crossfield rather than Balzac for this unit. Although strictly speaking such an approach follows the letter of the stratigraphic code, it clearly flies in the face of its intent by introducing unnecessary confusion. I have adopted a rather unconventional approach that preserves the existing nomenclature at the expense of legalistic precision.

Both the Balzac and Crossfield Formations have been retained in their originally defined sense in recognition of the generally accepted nomenclature. A new type section is designated for the Crossfield Formation near the southern limit of its outcrop. This section, which was originally described as the DeWinton Section by Stalker (1963, pp. 48-50), is located in a steep cutbank of the Bow River in 7-5-22-28W4. The section was described most recently by Proudfoot et al. (1981, p. 40), as a composite from a borehole drilled immediately adjacent to the outcrop (table 4).

The till of the Crossfield Formation typically contains abundant granitic and gneissic pebbles, cobbles, and boulders. The crystalline to carbonate ratio in the very coarse sand fraction is the highest of any unit in the Calgary area with values only rarely as low as 2.0. The sand content of the matrix is the highest, typically in the range from 30 to 35 percent; the montmorillonite to kaolinite plus chlorite ratio is also the highest of all the units. The carbonate content of the silt and clay fraction is the lowest of all the units in the Calgary area, with values typically less than 36 mL/g.

On the basis of compositional differences in a number of exposures in the southern part of the study area, two subdivisions of the Crossfield Formation

Table 5. Type section of the Calgary Formation (Tharin, 1960, pp. 73-77)

Unit		Thickness feet	Thickness metres
	Calgary silt		
A	Sand, windblown, calcareous, gray coarse, silty, pebbles rare, faintly bedded. Forms vertical cliff.	7.00	2.13
B	Soil, dark gray, sandy, carbonate flecks occasional pebble.	7.00	2.13
C	Sand, buff, coarse at base, finer upward includes western pebbles and granules. Occasional thin pebble lens; thickness variable.	33.00	10.06
D	Sand and clay interbedded, buff; highly contorted with 2-3 inch cross-bedded sand lenses enclosed in a thin shell of silty clay.	2.00	0.61
E	Clay, light tan; flat-lying, not contorted, persistent over entire cut. 17A/10A = 9.	0.17	0.05
F	Sand and clay interbedded, buff; highly contorted with 2-3 inch cross-bedded sand lenses enclosed in a thin shell of silty-clay.	3.00	0.91
G	Sand, buff, interbedded with thin clay bank. Graded bedding, no contortion.	1.67	0.51
H	Clay, buff, massive, minor contortion. 17A/10A = 1.48; CO_3 = 29%.	1.17	0.36
I	Sand and clay interbedded, buff; contorted as above.	3.67	1.12
J	Sand, buff, massive, one foot units, graded bedding.	6.00	1.83
K	Covered by slump.	80.00	24.38
L	Clay, dark gray, massive, thin silt beds.	30.00	9.14

have been recognized. An outcrop along the east side of a road crossing on the north side of a meltwater channel in 5-27-21-28W4 contains both units. An upper till unit with a texture of 28-34-38 and a crystalline to carbonate ratio of 6.1 overlies a lower till unit with a texture of 32-32-36 and a crystalline to carbonate ratio of 2.4 (figure 13).

The Crossfield Formation was deposited by a glacier that had a source in the Keewatin District to the west of Hudson Bay. This glacier advanced into the Calgary area from the northeast during the late Wisconsinan, probably during the latter part of that episode of glaciation (Clayton and Moran, 1982).

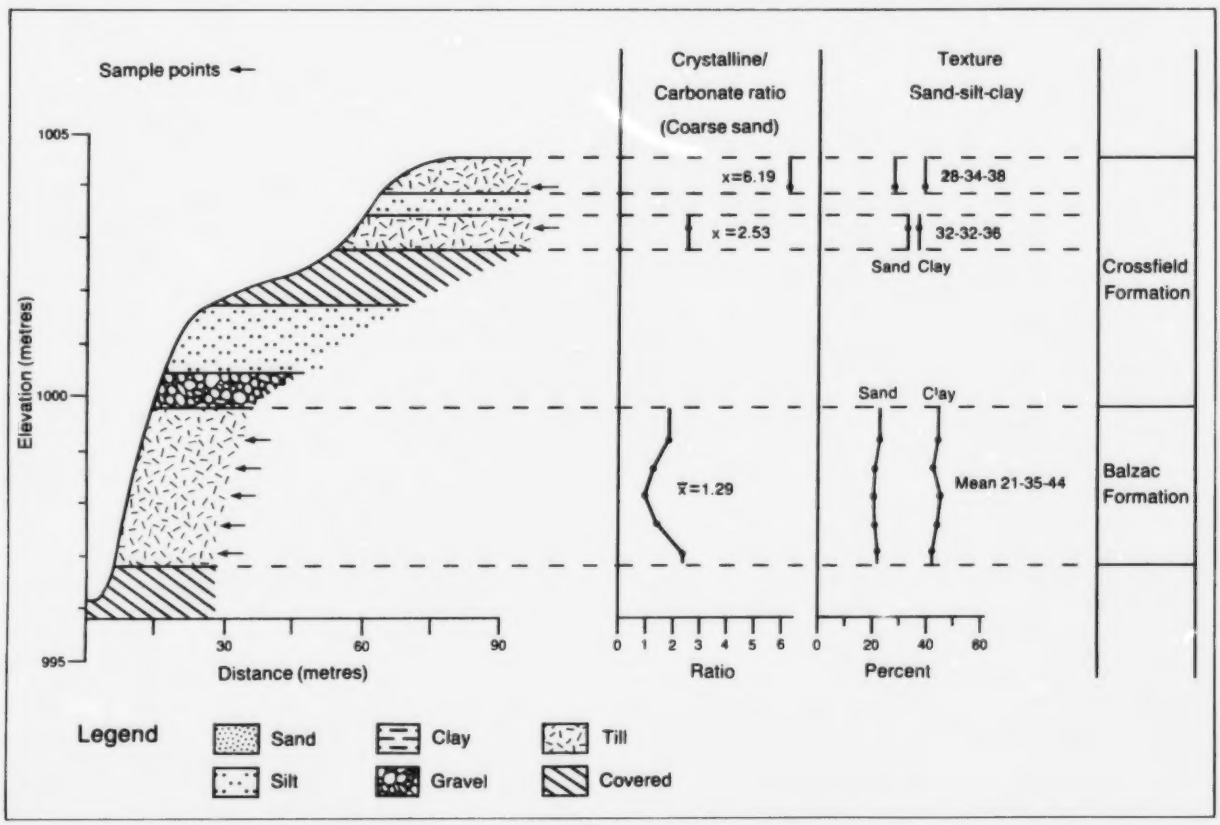


Figure 13. The Johnson ranch road section (5-27-21-28W4) showing two subdivisions within the Crossfield Formation, which here rests on the Lochend Formation

Calgary Formation

The Calgary Formation consists of silt, clay, and minor very fine sand and is widespread through the center of the study area (figure 5). It consists of lacustrine sediment related to all four glacial episodes that left sediment at the surface in the Calgary area.

The Calgary Formation was named the Calgary Silt by Tharin (1960, pp. 73-77) from exposures within the city of Calgary in SE4-35-24-2WS5 (table 5).

The Calgary Formation overlies each of the older till units at various places in the study area. It can be traced laterally into lacustrine sediment between the two till units of the Spy Hill Formation, in the lower part of the Lochend Formation and in the lower part of the Balzac Formation. No breaks have been recognized in the lacustrine sequence beyond the limits of the till units. Therefore, it has been impossible to subdivide the lacustrine sequence into units that can be related to the various till units.

Descriptive geology

Rocky Mountain foothills district

Description

The Rocky Mountain foothills district is a triangular shaped area of about 260 km² (100 mi²) in the southwestern and western part of the Priddis and Calgary 1:50 000 map sheets (figure 5). It is characterized by a series of north-northwest trending ridges separated by valleys that vary in width from 0.5 to 1.0 km. The ridges are composed of folded and faulted rocks of the Brazeau and Wapiabi Formations of Cretaceous age, which are draped by a thin veneer of till of the lower unit of the Spy Hill Formation. On the ridges the till varies in thickness from 0 to 3 or 4 m. The interridge valleys are filled with a considerable thickness of lacustrine clay of the Calgary Formation overlying till of the lower unit of the Spy Hill Formation (figure 4, cross section O-O′). On the basis of compositional differences in the till encountered in boreholes and in river cuts along Sheep Creek and the Highwood River south of the study area, more than one till unit is likely present in this district. Whether these different till units reflect compositional variation of depositional facies within the lower unit of the Spy Hill Formation or the deposits of earlier glaciations is not known.

Characteristics of stratigraphic units

The composition of the lower till unit of the Spy Hill Formation encountered in six boreholes in the Rocky Mountain foothills district is variable. Texture varies from sandy, clayey till (36-29-35) to silty till (13-63-24) to clayey till (28-28-44). Matrix carbonate content varies from 17 mL CO_2/g to 61 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite is generally low, ranging from 0.06 to 0.38. Limited data on coarse sand lithology indicate low crystalline to carbonate ratios, generally less than 0.08. No systematic patterns were detected in these compositional variations and they are interpreted to result from changes in amount and type of locally derived source material.

Resource potential

The only potential resource that has been identified in the district is a number of gravel deposits. Fluvial channel gravel has been mapped along the narrow flood plain of Fisher Creek and along Three Point Creek in the southern part of the district (figure 5). On the basis of limited surface exposure, this gravel is believed to be continuous, fairly coarse, and between 2 and 5 m thick (Shetsen, 1981, p. 24). Similar gravel deposits have been identified along Priddis Creek in sections 19 and 20 of 22-3-W5, sections 25 and 35 of 22-4-W5, and sections 2,3,4,9, and 20 of 23-4-W4 (figure 5). Only limited data on these gravel deposits are available. Shetsen (1981, figure 4, p. 71) indicates that this deposit varies in thickness from 4.5 to 8.5 m. She estimates minimum reserves as 1 600 000 m³.

Two small deposits of ice contact fluvial channel sediment have been mapped in sections 2 and 11 of 22-4-W5, section 1 of 21-4W5 and section 31 of 21-3W5 (figure 5), but nothing is known of the character of these deposits.

The flat-topped upland that lies just south of Priddis Creek in sections 24, 25, 26, 27, 28, 33 and 34 of 22-4-W5 is capped by gravel. The gravel is overlain by a sequence consisting of till of the lower unit of the Spy Hill Formation overlain by a discontinuous unit of clay. In testhole Cal 77-33 (8-33-22-4W5), 1.8 m of this overburden unit overlies 4.3 m of gravel. Further work is required to define the extent and characteristics of this gravel.

Factors influencing land use

The topography and geology of the foothills district result in a number of limitations to land use and construction.

1. The high relief and steep slopes of the bedrock cored ridges pose grade constraints for linear developments such as pipelines and roads. Erosion hazard is high wherever silt or calcareous till drapes these steep slopes.
2. Hard bedrock sandstone is encountered at depths less than 2 m over much of the district (Moran, 1986a, 1986c). This results in increased difficulty and cost for any construction involving excavation.
3. The relatively limited amount of till exposure combined with the high stone content of much of the till will make compactible fill material difficult to find in some areas.
4. The clayey lacustrine sediment that fills the interridge lowland area is susceptible to slope failure. Larger landslides have been mapped in 12-21-4-W5 and 3-22-4-W5 (Moran, 1986a). Other smaller slides are present, but are too small to show at the map scale. Existing slides have occurred where streams have excavated steep sided valleys into the clay.

Similar instability should be expected wherever roads cross steep slopes in the clay, especially at stream crossings, and in any artificial excavation of significant size.

Priddis valley district

Description

The Priddis valley district is a generally flat floored north-northwest trending lowland that varies in width from 2 to 5 km (figure 1). It is floored nearly everywhere by lacustrine clay overlying clayey till of the upper unit of the Spy Hill Formation. Generally the lacustrine sediment is flat to undulating, but, in places, as in the northern part of 21-3W5, the lacustrine sediment is hummocky as a result of deposition on stagnant ice.

The district is drained to the north by Priddis and Fish Creeks and to the south by Pothole and Three Point Creeks. Fluvial sediment in the district includes small amounts of both poorly sorted and well-sorted gravel along Three Point Creek and Pothole Creek, and significant areas of overbank alluvium along all the creeks (figure 5). As much as 0.46 m of Mazama Ash are present within the overbank sequence in the center of the district (testhole Cal 77-36, SW15-3-22-3W5).

Characteristics of stratigraphic units

Till of the upper unit of the Spy Hill Formation is present in eight boreholes in the district. It generally contains less than 20 percent sand and varies from being dominantly clayey in the north and west of the district (Cal 77-20, 77-15), to dominantly silty in the central and southeastern part of the district (Cal 77-13, 77-35, 76-107, and 76-92), to containing about the same amount of silt and clay in the south and west part of the district. Presumably these differences reflect differences in the composition of bedrock and lake sediment that was incorporated into the glacier. The matrix carbonate content of the till has a relatively narrow range from 38 to 52 mL CO_2/g, with a mean value of 44 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite has a mean value of 0.51 with only one of four testholes having a value lower than 0.60. Coarse sand data that are available from one testhole indicate a ratio of crystalline to carbonate grains of 0.09.

Till of the lower unit of the Spy Hill Formation is present beneath the upper unit at four sites. This till is generally sandier than the upper unit, with a mean sand content of 30 percent; in every case, clay is more abundant than silt. The carbonate content is about half that of the upper unit with a mean value of 22 mL CO_2/g. The montmorillonite to kaolinite plus chlorite ratio is lower, having a mean value of 0.31. Only one of three sites has a value greater than 0.25. No data are available on the coarse sand composition.

Resource potential

Gravel deposits in the Priddis valley district are of two types. Fluvial channel gravel of Holocene age occurs along Priddis Creek and Fish Creek in the north, and Pothole Creek and Threepoint Creek in the south (figure 5). Ice contact fluvial channel gravel occurs in the hummocky moraine complex along the southeast side of the district (figure 5).

At the northern end of the district the terraces along the valley of Fish Creek at the town of Priddis (22-22-3W5) consist of about 2 m of gravel overlain by 0-0.6 m of silt and fine sand (Shetsen, 1981, figure 4, p. 71). Shetsen (1981, p. 71) estimates minimum reserves of 200 000 m^3. In the southern part of the district, terraces along Three Point Creek contain 1.2 to 3.0 m of gravel overlain by 0 to 1.0 m of silt and fine sand; the estimated minimum reserves are 700 000 m^3 (Shetsen, 1981, figure 4, p. 73). Both these deposits are more extensive than the portions included in Shetsen's reserve estimates, so both these figures are conservative.

At the southern end of the district, in 18-212W5 and 13-21-3-W5, an ice contact fluvial channel deposit contains from 1.8 to 5.5 m of gravel and 0 to 1.5 m of sandy overburden; Shetsen (1981, figure 4, p. 73) estimated minimum gravel reserves as 350 000 m^3. A similar smaller deposit in sections 25, 26 and 35, of Tp-21-3-W5 contains an estimated minimum reserve of 50 000 m^3 in an esker ridge that contains as much as 4 m of gravel (Shetsen, 1981, figure 4, p. 73). Both these deposits are larger than the portion included in Shetsen's estimates and the estimates are conservative.

Factors affecting land use

The only factors that may have impact on any land use decisions or operations are the shallow bedrock along the western and, in places, eastern edge of the district, and the thick lacustrine clay that forms the surface over most of the district. The clay may cause some slope instability in places where deep cuts are required and will be difficult to handle in excavations when wet. Other than these minor factors, little problem is expected from any of the material in the district.

Priddis Hills district

Description

The Priddis Hills district comprises an area of about 165 km^2 in the south central part of the Priddis 1:50 000 map sheet (figure 1). It is a dissected upland with elevations in excess of 1340 m (4400 ft). Rock is only rarely exposed so the structure underlying the upland can only be guessed, but on the basis of the morphology it appears likely that the bedrock is flat lying or gently dipping over most of the district. Small northwest-southeast trending ridges along the western edge of the upland appear to mark the easternmost extent of the foothills folded belt. On this basis the contact between the Brazeau and Wapiabi Formations to the west and the Porcupine Hills Formation to the east, has been mapped along the western part of the Priddis Hills (Moran, 1986a). In places, the bedrock is only thinly draped by till of the Spy Hill Formation. Over most of the upland, however, the till cover is metres to tens of metres thick. Hummocky stagnation moraine and collapsed superglacial lake sediment fill many of the valleys that were incised into the upland prior to its being glaciated.

The highest parts of the upland are covered by till of the lower unit of the Spy Hill Formation, which has been overlapped by the upper unit of the formation at lower elevations (figure 5). The boundary between the two units is obscure in most places and its location is only approximate. The presence of inclusions of the lower unit in the upper unit, the presence of areas of very thin till of the upper unit, and the abundance of local bedrock in both units combine to make location of the contact very difficult in most areas.

Characteristics of stratigraphic units

In the Priddis Hills district, ten testholes and eight surface sites exposed till of the upper unit of the Spy Hill Formation. In the eastern part of the district the till is generally more sandy (25 to 30 percent sand), than in the west, where it generally contains 15 to 23 percent sand. Roughly an equal number of locations exposed till that contains dominantly clay (six), silt (five), or silt and clay in roughly equal proportions (seven). Matrix carbonate content varied over a narrow range from 34 to 43 mL CO_2/g, with a mean of 38 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite was below 0.50 in only one of nine sites with a mean value of 0.60; along the eastern edge of the district this ratio is generally above 0.75. The ratio of crystalline to carbonate grains in the very coarse sand fraction ranged from 0.04 to 0.34 with a mean of 0.13 for eight locations.

In six testholes, till of the lower unit of the Spy Hill Formation was intersected beneath the upper unit. In one testhole and three surface exposures the lower unit is the uppermost till present. It is generally sandier in the north and west with sand content ranging from 23 to 30 percent, elsewhere values range from 15 to 20 percent sand. At six sites, generally in the southern part of the district, the till is dominantly clayey; in only one site is silt dominant. In the remaining three sites silt and clay are roughly equal. The carbonate content of the till is generally slightly lower than in the upper unit, but in two testholes this pattern is reversed. The mean carbonate content is about 36 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite is generally lower than in the upper unit; two of five sites had values of 0.50 or greater with a mean value of 0.43. At five sites, the ratio of crystalline to carbonate grains in the coarse sand is less than 0.03, which is substantially less than in the upper unit. Like the upper unit the montmorillonite to kaolinite plus chlorite and crystalline to carbonate ratios are higher along the eastern edge of the district.

Resource potential

There are almost no potential aggregate resources within the district. A series of small, isolated deposits of ice contact sand and gravel have been mapped in the western and southern parts of the district, largely on the basis of morphology. Some of these, as in SW3-29-21-2W5, are known to contain poorly sorted sand and gravel, but little is known of the composition of most of these features.

Factors affecting land use

The shallow depth to rock and steep slopes of much of the eastern and northern parts of the district, combined with the abundance of stones in the till, will increase construction costs of all structures involving excavation. No particular hazards are expected anywhere in the district.

Sarcee upland district

Description

The Sarcee upland district comprises an area of about 155 km² in the west central part of the study area (figure 1). Most of the district lies in the Sarcee Indian Reserve and is known only from aerial photographic interpretation. Two testholes in the northern part and one in the southern part of the district provide the only data on subsurface conditions in the district.

The Sarcee upland district is a broad upland area between the valleys of Fish Creek in the south and the Elbow River in the north. Elevations as high as 1205 m (3950 ft) occur in the eastern part of the area. The terrain reaches 1340 m (4400 ft) on isolated ridges in the west, adjacent to the Rocky Mountain foothills district. The east-west trending central upland of the district is bisected by an east-southeast trending meltwater channel that was cut to about 1160 m (3800 ft) by southward draining overflow of a glacial lake in the valley of the Elbow River.

Characteristics of stratigraphic units

In the absence of exposures, the structure and stratigraphy of the bedrock have been inferred from the morphology, as was the case in the Priddis Hills district. It is inferred that most of the district is underlain by flat-lying or gently dipping rocks of the Porcupine Hills Formation. Folded beds of the Brazeau and Wapiabi Formation are believed to be present along the western edge of the district.

The till cover on the Sarcee upland is believed to be nearly continuous. It consists of till of the lower unit of the Spy Hill Formation, which has been overlapped by the upper unit in the eastern part of the district (figure 5). On the north side of the district, both units of the Spy Hill Formation are composed of clayey, silty till, containing 15 to 20 percent sand. Both are very similar to their equivalents to the north in the Springbank district. In the southern part of the district, the till of the Spy Hill Formation is sandier and less clayey than in the north.

Resource potential

Two small ice contact sand or sand and gravel deposits have been mapped in the southern part of the district in sections 33 and 34-22-3W5 (figure 5); Shetsen (1981, figure 4) indicates that the westernmost one is fine sand. An area of sand or gravel is mapped on the basis of aerial photo interpretation along the upper reach of Six Mile Creek in the center of the Sarcee Indian Reserve (figure 5). Nothing is known of the composition of this material, nor that of several ice contact gravel bodies mapped on a similar basis on the top of the upland to the north and east (figure 5). An extensive area of gravel occupies the eastern end of the district and extends across into the Calgary city district. This gravel has been exploited in a series of pits along the eastern boundary of the Sarcee Indian

Reserve. No data on the characteristics or reserves of these deposits have been obtained.

Lloyd Lake district

Description

The Lloyd Lake district is an irregular shaped area of about 370 km² in the eastern part of the Priddis 1:50 000 map sheet. It is bounded on the west by the Priddis Hills, on the north by the Sarcee upland, and on the east by the lower Bow valley districts (figure 1). The southeastern boundary with the DeWinton district is arbitrarily drawn along Wilson Coulee, a major meltwater channel. The district is characterized by a bench that extends eastward from the foot of the Priddis Hills at elevations reaching 1175 m (3850 ft) in the north and 1160 m (3800 ft) in the south. The bench is underlain by flat-lying to gently dipping beds of the Porcupine Hills Formation that have been dissected by a series of northeastward and eastward draining valleys.

The central part of the Lloyd Lake district is drained by Pine Creek, which rises in the Priddis Hills. The valley of Fish Creek cuts across the northern edge of the district. The district is transected by a series of glacial lake outlet spillways that trend northwest-southeast in the west and nearly north-south in the east. The highest spillway connects the valley of Fish Creek with Lloyd Lake. A second part of this system consists of a pair of narrow, deep trenches cut into rock across the divide between the basins of Lloyd Lake and Pine Creek (figure 5).

This same high-level system of spillways is recognized farther south as a small wind gap, and as a valley occupied by the upper part of the Wilson Coulee (figure 5). Two lower valleys that are cut into bedrock in the eastern edge of the district were marginal to the retreating glacier that deposited the upper unit of the Spy Hill Formation and the Lochend Formation (figure 5). The upper channel is traced into the major meltwater channel that heads at DeWinton and contains the lower part of Wilson Coulee (figure 5). The lower of these channels ends in a gravel deposit just south of Academy (figure 5). The eastern margin of the district is marked by yet another channel, which follows the western margin of the Crossfield Formation.

In the upland areas, the bedrock is overlain by till of the Spy Hill and Lochend Formations (figure 5). In the valleys, the fill consists of silty lake sediment interbedded with till of the same formations.

Characteristics of stratigraphic units

The surface till throughout most of the district is the upper unit of the Spy Hill Formation. Till of the Lochend Formation is at the surface along the eastern edge of the district (figure 5).

Samples of the upper unit of the Spy Hill Formation were analyzed in 23 boreholes as well as 12 surface exposures in the district. At 28 sites these samples fall into a relatively narrow compositional group with a mean textural composition of 20-42-38 (sand-silt-clay). The mean carbonate composition is 48 mL CO_2/g (14 sites); the mean ratio of montmorillonite to kaolinite plus chlorite is 0.51 (15 sites); and the mean ratio of crystalline to carbonate grains in the coarse sand fraction is 0.13 (18 sites) with a range of 0.01 to 0.34.

At four sites near the eastern edge of its outcrop, the till of the upper unit of the Spy Hill Formation is significantly more clayey and less sandy with a mean textural composition of 10-40-50 (sand-silt-clay). No data on carbonate mineralogy are available but the mean ratio of montmorillonite to kaolinite plus chlorite is 0.60 (three sites) and the ratio of crystalline to carbonate grains in the coarse sand fraction is 0.14 at one site. These compositional differences appear consistent with the higher clay content, which probably reflects incorporation of lacustrine clay. At two sites the till of the upper unit of the Spy Hill Formation is somewhat more sandy and less clayey than usual. The mineralogical composition of the till at these sites is similar to that of the unit in general.

At nine sites, till of the lower unit of the Spy Hill Formation was encountered beneath till of the upper unit. The composition of this till is more varied than that of the upper unit, presumably reflecting compositional variability in the underlying bedrock. At two sites it is significantly more sandy, at three sites it is slightly sandier and at three sites it is significantly less sandy than the overlying till. The matrix carbonate content is less than in the overlying till with a mean value of 35 mL CO_2/g at eight sites. At two sites the ratio of montmorillonite to kaolinite plus chlorite is lower than in the overlying till and at four sites it is higher. Coarse sand data are available from three sites and the ratio of crystalline to carbonate grains is consistently lower than in the upper unit with a mean value of 0.051.

Till of the Lochend Formation was recognized in three boreholes and four surface sites along the eastern edge of the district. In two boreholes and one outcrop the till is silty clayey with a mean texture of 23-39-38. In the remaining four sites, it is much more clayey with a mean composition of 9-38-53. Limited data on carbonate content for all samples indicate a wide range from 15 to 51 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite is relatively high with a mean value of 0.72. The ratio of crystalline to carbonate grains in the coarse sand has a similarly wide range, from 0.43 to 2.28 with a mean for six sites of 1.09.

Resource potential

A series of sand and gravel deposits that are associated with ice marginal meltwater channels occur in the Lloyd Lake district.

Gravel deposits floor the entire length of the 300 m wide channel that extends from 14-31-22-1W5 to 12-20-22W5 (figure 5). Shetsen (1981, p. 72) indicates that this deposit contains a minimum of 225 000 m³ of gravel that ranges in thickness from 2.0 to 4.5 m beneath a cover of 0 to 1.5 m of silt and till.

A second small deposit, which contains 60 000 m³ of gravel (Shetsen, 1981, p. 72) is present at the north end of a channel in 2-5-23-1W5 and 15-32-22-1W5.

A major ice contact fluvial deposit in 9-22-1W5 (figure 5) contains as much as 1 000 000 m³ of gravel (Shetsen, 1981, p. 72). This deposit, which has a complex origin, consists of gravel that ranges in thickness

from 2.5 to 7.5 m and is overlain by 0 to 0.5 m of silt (Shetsen, 1981, p. 72).

A thin deltaic deposit that contains a minimum of 150 000 m^3 of gravel is located in 1-22-1W5 (Shetsen, 1981, p. 72). This gravel ranges in thickness from 2.5 to 3.5 m and is overlain by 0.8 to 1.0 m of silt.

Other gravel and sand deposits are present along the eastern edge of the district in sections 21 and 28-22-1W5 beneath till and along the meltwater channel that extends from Midnapore south to 14-22-1W5.

A borehole in the flat upland in sections 7, 8, 17, and 18-22-1-W5 encountered gravel beneath about 10 m of till of the Spy Hill Formation. No data on the character, thickness, or extent of this deposit are available. On the basis of the setting, however, the deposit could cover as much as 5 km^2.

Another deposit of gravelly sand and sand that was deposited as a delta along the upper part of Wilson Coulee is situated in 11-21-1W5 (figure 5). A similar although smaller deposit lies along a small unnamed creek, just to the west of this deposit (figure 5). There are no data on either the thickness or character of these deposits.

Gravel deposits floor the valley of Fish Creek along the northern edge of the district. On the basis of very limited data, the thickness of this gravel is estimated to be generally 2 to 4 m, with a discontinuous silt cover that ranges in thickness from 0 to 2 m.

Factors affecting land use

In several areas within the district, bedrock is encountered less than 2 m below the surface (Moran, 1986a). In these areas, increased costs of excavation are anticipated.

The silty lake sediment in the northwestern and central parts of the area is likely to be susceptible to erosion on steep, unvegetated slopes, although no data are available to support this concern.

DeWinton district

Description

The DeWinton district is an area of about 165 km^2 in the southeastern corner of the study area. It is bounded on the west by the Lloyd Lake district at the DeWinton-Wilson Coulee spillway and on the north by the lower Bow valley district (figure 1). Most of the district is characterized by a very thin veneer of till of the Spy Hill and Lochend Formations draped over an upland consisting of flat-lying to gently dipping beds of the Porcupine Hills Formation. Only in the northeastern part of the area and east of the Highwood River is thicker drift encountered. In these areas, till of the Crossfield Formation or fluvial sand overlying the Crossfield Formation makes up the surface unit.

As in the Lloyd Lake district to the northwest, this area is characterized by a series of northwest-southeast trending glacial lake spillways that are cut into bedrock where they cross the divide between the northeast-southwest trending valleys (figure 5).

The western margins of the Lochend and Crossfield Formations are marked by well-defined ice marginal ridges ("end moraines") across most of the DeWinton district.

Characteristics of stratigraphic units

Till of the upper unit of the Spy Hill Formation was recognized in the southwestern corner of the DeWinton district. This till is characterized in outcrop by common pink and purple quartzite pebbles and uncommon to rare granitic pebbles. The crystalline to carbonate ratio in the coarse sand fraction ranges from 0.04 to 0.41 with a mean value of 0.14. Two distinctive textural groupings were recognized among the samples of this unit: a more clayey group with a mean composition of 16-44-40 and a slightly more sandy and silty group with a mean composition of 21-46-33. No clear distributional pattern characterizes these two textural groupings except a tendency for the more clayey group to be concentrated in the eastern part of the area. In one outcrop exposed on the left abutment of a small dam at Strathmore School (16-11-21-1W5), the more sandy and silty till overlies the more clayey till. Till of the Spy Hill Formation was recognized in only one testhole in the district, Cal 75-1 (1-1-22-1W5). At this location the till is related to the more clayey textural grouping.

The Lochend Formation is recognized to the east of the outcrop of the Spy Hill Formation (figure 5). The crystalline to carbonate ratio of coarse sand from samples in surface exposures ranges from 0.55 to 2.93. Three textural and compositional groupings have been recognized within those samples. One group, characterized by a grain size composition of 23-47-30 and a crystalline to carbonate ratio in the coarse sand of 1.12, occurs along the margin of the unit with the Spy Hill Formation (figure 5). A second group of samples, characterized by a texture of 32-40-28 and a crystalline to carbonate ratio in the coarse sand of 2.18, occurs along and about 3 km behind the western margin of the unit. The third group, with a texture of 17-41-42 and a crystalline to carbonate ratio in the coarse sand of 1.12, occurs generally further away from the margin. Two boreholes, Cal 76-109 (1-7-21-28W4) and Cal 75-7 (5-1-21-28W4) encountered till of the Lochend Formation.

Where the Balzac Formation is not present, separation of tills of the Lochend and Crossfield Formations may be difficult because of similar compositions. This problem is discussed at considerable length below, because of difficulties in clarifying stratigraphic relationships in the lower Bow valley and Lloyd Lake districts.

Till of the Balzac Formation has not been identified beyond the limit of till of the Crossfield Formation. It is present only in the northeastern part of the district beneath the Crossfield Formation. In one outcrop, the till is clayey, silty (21-35-44) and has a crystalline to carbonate ratio in the coarse sand of 1.29 (figure 13).

Till of the Crossfield Formation is the surface unit throughout the northern part of the district (figure 5). It is the sandiest till unit in the district with a mean composition of 31-33-36. The ratio of crystalline to carbonate grains in the coarse sand is also the highest, with a range of 2.76 to 7.07 and a mean of 3.96. Two boreholes in the district (Cal 76-75 and Cal 75-110) sampled till of the Crossfield Formation; the texture of the till at these locations is the same as in the surface exposures, with a mean of 32-32-36. The carbonate content (24 mL CO_2/g), is the lowest of all the units and

the montmorillonite to kaolinite plus chlorite ratio is 0.87.

Resource potential

Minor gravel deposits occur in several places in the DeWinton district where short-lived meltwater streams flowed between the wasting ice to the northeast and the major bedrock upland in the south central part of the district. A small pit in 13-27-21-29W4 exploits a delta along the margin of the retreating glacier that deposited the Lochend Formation (figure 5). A second small deposit occurs in LSDs 9, 10, and 11 of 25-21-29W4 (figure 2). Shetsen (1981, p. 63, figure 9) indicates that the deposit, which is as much as 3 m thick and is overlain by as much as 1 m of clay, contains a minimum of 450 000 m^3 of sand. A thin layer of gravel that rarely exceeds one metre in thickness floors the meltwater channel that extends from SW31-21-23W4 to SE28-21-28W4 (figure 5). None of these deposits contains reserves adequate for more than local use.

Major gravel deposits occur as ice contact fluvial deposits on the uplands beside and as terraces along the Highwood River (figure 5). Shetsen (1981, p. 63, figure 9) indicates that the ice contact deposits in sections 16 and 21 of 22-28W4 contain 90 to 95 percent sand along with minor gravel. The deposit, which is as much as 4 m thick, has a minimum volume of 400 000 m^3. The fluvial terraces consist of 30 to 80 percent fine to coarse gravel that is 3.5 to 5.0 m thick and is overlain by 0 to 1.8 m of silty overburden (Shetsen, 1981, p. 63); reserves are estimated at a minimum of 2500 m^3.

In a pit along Highway 2, just east of the town of DeWinton, in 31-21-29W4, claystone of the Porcupine Hills Formation is quarried for the manufacture of expanded aggregate.

Factors affecting land use

The shallow depth to bedrock in the southwestern part of the district and along the meltwater channel in the northeast is the major factor influencing land use in the district. The hard bedrock may pose problems for excavation in this area.

Springbank district

Description

The Springbank district consists of an irregularly shaped area of about 140 km^2 (55 mi^2) in the southwestern part of the Calgary 1:50 000 map sheet (figure 1). It is bounded by the Rocky Mountain foothills, Sarcee hills, Broadcast Hill and upper Bow valley districts on the west, south, east, and north, respectively.

Except for the valley of the Elbow River, which forms its southern margin, the district consists of a low relief, undulating to rolling plain underlain nearly everywhere by silt or clay of the Calgary Formation (figure 5). Till of the Spy Hill Formation is exposed in gullies and cutbanks along the Bow and Elbow Rivers at the eastern edge of the district, just west of Broadcast Hill (figure 5). The low bedrock divide separating the drainage of the Bow and Elbow Rivers, consists of flat to gently dipping beds of the Porcupine Hills Formation, which are exposed only in limited outcrops along the valley of the Elbow River. The rock is thinly draped by till of the Spy Hill Formation, which is in turn overlain by lacustrine sediment of the Calgary Formation (figure 3, cross sections A-A′, B-B′).

Characteristics of stratigraphic units

Throughout the northern part and in the southeast corner of the district, both the upper and lower till units of the Spy Hill Formation are present. Elsewhere, only the lower unit is present. The most pronounced difference between these two till units is in the northwestern part of the district at sites Cal 78-8 and 78-9 where the lower unit is significantly more sandy than the upper unit (figure 3, cross section A-A′). Elsewhere the two units have nearly the same textural composition, although there is a small difference in nearly all locations. The carbonate content of the lower unit is generally slightly higher than in the upper unit, although the difference is small. The principal compositional distinction between the two units is the significantly higher ratios of montmorillonite to kaolinite plus chlorite, and crystalline to carbonate, in the coarse sand fraction in the upper unit.

Resource potential

Only two gravel deposits have been identified within the district: a small, deltaic deposit at the mouth of the meltwater channel in NW23-24-3W5 and a major deposit underlying the floor of the Elbow River valley along its entire length. The small, deltaic deposit is known to contain sand and gravelly sand, but the thickness and extent of the deposit is not known. Shetsen (1981, p. 77) indicates that the gravel flooring the Elbow River ranges in thickness from 1.8 to 6.5 m with a mean thickness of 3 m. It is overlain by 0 to 1.7 m of silt and minimum reserves are estimated at 75 000 m^3.

Factors affecting land use

The most widespread factor likely to influence land use in the Springbank district is the potential susceptibility to erosion of the silty lake sediment that occurs throughout the district. On steep slopes, such as along the valley of the Elbow River in the eastern part of the district, removal of vegetation can result in significant and rapid rill erosion.

The only other factor considered potentially significant is the occurrence of bedrock at depths less than 2 m in limited areas within the district, especially in the northeastern corner and potentially along the western edge.

Broadcast Hill district

Description

The Broadcast Hill district consists of the slopes and top of the Broadcast Hill upland, an area of about 50 km^2 (20 mi^2) located at the western edge of the City of Calgary between the Bow and Elbow River valleys (figure 1). It rises about 60 m (200 ft) above the plain of the Springbank district, 120 m (400 ft) above high

fluvial terraces along the Bow valley to the north, and 150 to 180 m (500 to 600 ft) above the floors of the Bow and Elbow Rivers. The top of the hill is a flat to undulating plain broken by a 15 to 20 m high east-facing scarp about 2 km from the western edge. The sides of the hill drop away steeply on every side.

The Broadcast Hill upland is an erosional remnant of flat-lying beds of the Porcupine Hills Formation. It is capped everywhere by a layer of Tertiary gravel, which is in turn overlain by till of the Spy Hill Formation. The flanks of the hill are composed of till or bedrock draped by colluvium (figure 5). The till cover is thicker on the south and west facing slopes, with bedrock outcrops common along the northern and especially the eastern slopes of the hill.

Characteristics of stratigraphic units

Both till units of the Spy Hill Formation are mapped on the Broadcast Hill upland with the lower unit outcropping only at the extreme western end of the upland (figure 5). The two units have not been recognized together in either outcrop or borehole in the district. The very limited analytical data from the district indicates that both tills have a similar textural composition, which is characterized by higher sand and lower clay content than in either unit in adjacent districts. Presumably this reflects greater incorporation of lacustrine sediment in the surrounding low-lying areas. Texturally, the till resembles that of the lower unit of the Spy Hill Formation in the western part of the Springbank District.

Resource potential

Nearly the entire upland is underlain by gravel of Tertiary age. The gravel is overlain by till that ranges in thickness from 0.5 to 4.5 m with a mean thickness of 2.0 m. The gravel deposit itself contains minimum estimated reserves of 50 000 000 m^3 (Shetsen, 1981, p. 77). The gravel has a mean thickness of 5 m but in places is more than 10 m thick.

Factors affecting land use

The steep slopes and shallow depth to bedrock that characterize much of the edge of the Broadcast Hill upland are the principal factors affecting construction in the district. In places, coarse gravel is encountered in excavation and can result in increased costs.

Big Hill-Cochrane district

Description

The Big Hill-Cochrane district consists of about 200 km^2 (75 mi^2) of upland along the north side of the Bow River valley west of Calgary (figure 1). It extends from Nose Hill, in the northern part of the City of Calgary, westward to the western edge of the study area, just west of Cochrane. Like the Broadcast Hill upland, the district is an erosional outlier, consisting of a gravel-capped bedrock upland. The bedrock consists of flat-lying to gently dipping beds of the Porcupine Hills Formation. The gravel cap is considered to be Tertiary gravel although some authors have considered part of the gravel to be of Pleistocene age (Rutter and Wyder, 1969; Nowack, 1981). The Big Hill-Cochrane upland is draped by till of both units of the Spy Hill Formation, as well as the Lochend and Balzac Formations (figure 5). The thickness of the till cover over the Tertiary gravel ranges from about 2.5 m in the eastern and western parts of the district to more than 30 m in places in the central part of the district (figure 14).

In the east and central part of the district, the hummocky dead ice moraine topography of the upper unit of the Spy Hill Formation and the Lochend Formation contains numerous bodies of lacustrine and fluvial sediment (figure 5). Some of the lakes are discrete, well-defined, ice-walled lakes; in others, the clay forms unmappable complexes with till. The distribution of collapsed fluvial gravel indicates that the ice in the Bow River valley melted first while significant thicknesses of ice remained on the northeast side of the Big Hill upland.

Characteristics of stratigraphic units

The northeastern edge of the district is draped by till of the Lochend Formation. The southwestern edge of the district is covered by till of the upper unit of the Spy Hill Formation. The western portion of the district is covered by a thin veneer of till of the lower unit of the Spy Hill Formation, which is also present, in places, beneath the two younger units throughout the district (figure 3, cross section C-C′). The compositional characteristics of these three till units, as sampled in boreholes, are summarized in table 6. Texturally, all three units are similar; the Lochend Formation is highest in sand and lowest in clay. The lower unit of the Spy Hill Formation has a significantly lower montmorillonite to kaolinite plus chlorite ratio (m/k + cl) and crystalline to carbonate ratio than the other two units (table 6). In general, differences between units are greater in individual testholes than shown in the summary (for example, figure 9).

Resource potential

Numerous gravel deposits occur throughout the district. By far the largest are the gravel deposits of Tertiary age that cap the entire upland (figures 2 and 14). A series of large ice contact esker and esker delta deposits line the southern edge of the upland in the east (figure 5). The third type of deposit includes small, isolated ice contact deposits that occur throughout the district (figure 5).

Table 6. Summary of compositional data of stratigraphic units in the Big Hill-Cochrane district

	Sites	Texture Percent Sand (standard deviation)	Silt	Clay	Carbonate Content mL CO_2/g (SD)	Clay Mineralogy m/k + cl	Coarse Sand xln/CO_3
Lochend	2	20 (0.7)	34	46 (3.5)	55 (15.6)	0.56 -	1.75 -
Upper Spy Hill	3	15 (1.5)	55	30 (5.0)	52 (8.9)	0.63 (0.21)	-
Lower Spy Hill	7	17 (2.5)	33	50 (3.6)	60 (7.3)	0.29 (0.14)	0.06 -

The Tertiary gravel deposits capping the Big Hill upland were estimated by Shetsen (1981, p. 74) to contain minimum reserves of 65 000 000 m³. This estimate is very conservative, taking into account only the eastern part of the deposit where the till overburden is less than 3 to 5 m thick. The entire deposit is estimated to contain 185 000 000 m³ of gravel, although much of this could never be recovered because of the great thickness of overburden which exceeds 30 m in places (figure 14). The overburden in the western part of the deposit, however, is thin enough that the potential recoverable reserves could be significantly increased. The thickness of the deposit is not well known because few testholes have been able to penetrate its total thickness, but as much as 24.7 m of gravel have been reported.

Much of the gravel in the large ice contact esker and esker delta deposits that are mapped along Crowchild Trail westward from Silver Springs (figure 5) has been mined or covered by construction. Nonetheless, Shetsen (1981, p. 74) estimated reserves of 770 000 m³ for the areas remaining. The gravel, which varies in thickness from 2.0 to 18.0 m, generally crops out at the surface, but, in places, is capped by as much as 3.5 m of silt. A number of small eskers that are believed to contain gravel are mapped in the district (figure 5). Shetsen (1981, p. 73) indicated that these deposits contain from 2 to 6 m of gravel, with reserves of individual eskers ranging from 20 000 to 200 000 m³.

Factors affecting land use

Bedrock and coarse gravel are encountered at shallow depths in many places in the eastern and western part of the upland as well as on the steep northeast and southwest facing slopes of the upland (Moran, 1986c). In these places, costs of excavation are expected to be high. Heavy clay in the ice contact lacustrine deposits in the central part of the district, as well as in the till of the Spy Hill Formation, results in problems of trafficability during wet weather. The fine sand north of Cochrane is susceptible to erosion on steep, unvegetated slopes.

Beddington district

Description

The Beddington district is a triangular-shaped area of 150 km² (60 mi²) in the northeastern part of the Calgary 1:50 000 map sheet. It is bordered on the south by the Big Hill-Cochrane district and on the east by the Delacour-Shepard district (figure 1). Flat-lying to gently

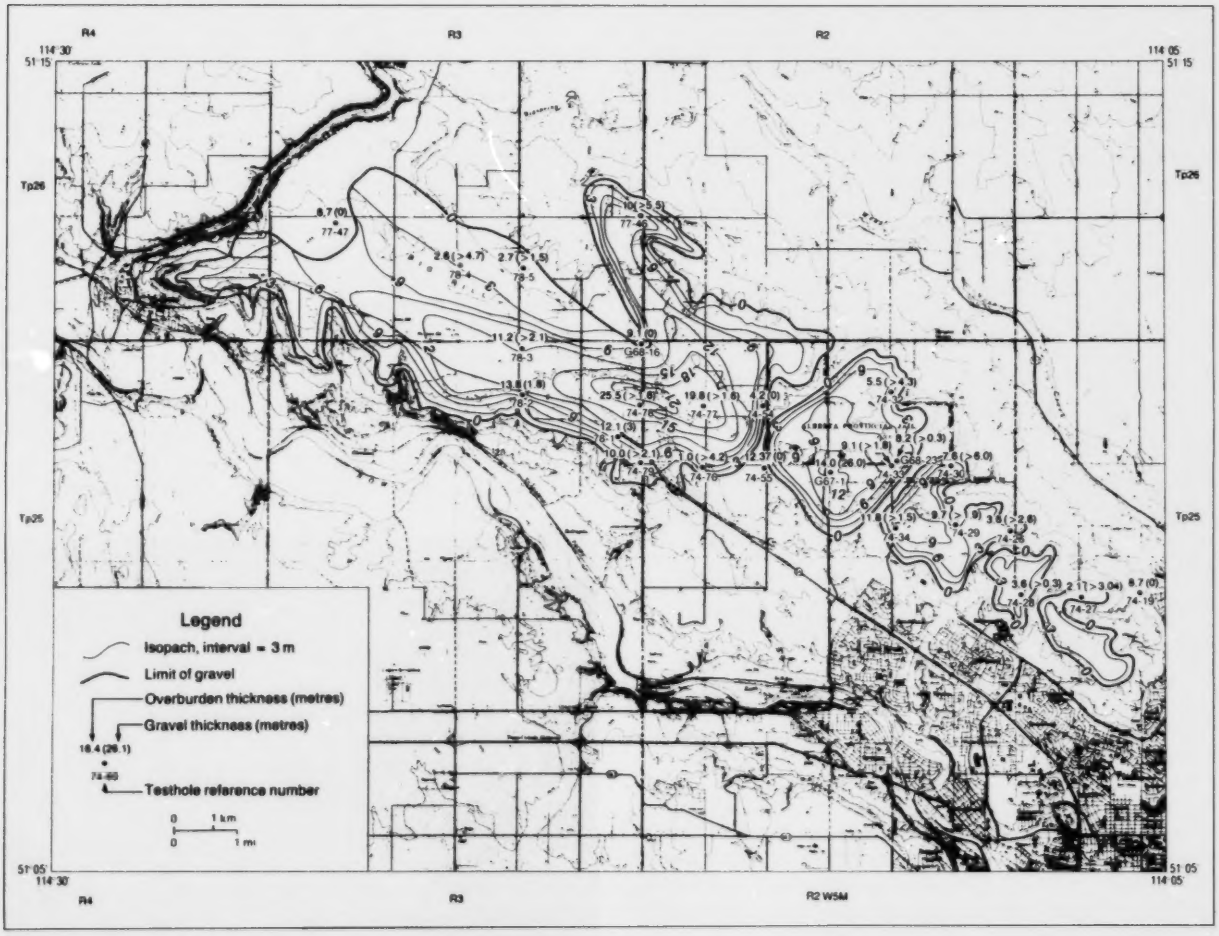


Figure 14. The thickness of overburden covering the Tertiary gravel in the Big Hill-Cochrane district

dipping rocks of the Porcupine Hills Formation are thinly draped by till of the Balzac Formation over most of the district (figure 5). Along the eastern edge of the district and parallel to the southwestern margin, the valleys of Nose and Beddington Creeks, respectively, are incised into the rock. The Beddington Creek valley postdates the deposition of the Balzac Formation, but the Nose Creek valley appears to predate it. Undissected till of the Balzac Formation occurs from place to place along the valley floor. In the west, till of the Lochend Formation crops out at the surface. In most of the district, the till is from 0 to 10 m thick. Drift as thick as 20 m has been encountered in places along the western edges of the valleys of Beddington Creek and Nose Creek. Along Nose Creek as much as 6 m of silty lacustrine sediment that underlies till is included in the Balzac Formation.

Characteristics of stratigraphic units

In the Beddington district, till of the Balzac Formation falls into two textural classes. Silty-clayey pebble loam with a mean sand-silt-clay composition of about 15-40-45 makes up about 75 percent of the 60 surface samples. The remaining 25 percent of the samples have a mean texture of about 24-48-28. At seven subsurface sites, the mean texture is 17-47-36. The matrix carbonate content is variable with a mean of 56 mL CO_2/g.

The mean ratio of crystalline to carbonate grains in the very coarse sand fraction from subsurface samples was 0.37, whereas in 46 surface sites it was 0.24.

In five testholes, a second till was encountered beneath the Balzac Formation. In three of these holes near the southwestern edge of the Balzac Formation, this second till can be confidently recognized as the Lochend Formation. In two of these locations the till of the Lochend Formation has a matrix texture of 24-37-39 (sand-silt-clay). The carbonate content is about 50 mL CO_2/g and the crystalline to carbonate ratio of one sample from site 77-45 is 0.36. At the third site, 74-24, the till of the Lochend Formation is considerably less sandy and more clayey.

In two holes along the eastern edge of the district, the lower till is very silty with a mean texture of 20-54-26; the mean carbonate content is 58 mL CO_2/g and the crystalline to carbonate ratio of the coarse sand fraction is 0.33. This till is likely the Lochend Formation, but the correlation is not as clear as for the sites farther west.

The Lochend Formation was sampled at five surface sites, three beyond the limit of the Balzac and two behind the limit. The mean texture of the till at these sites was 16-41-43, and the ratio of crystalline to carbonate grains in the coarse sand ranged from 0.62 to 1.94, with a mean of 1.26.

Resource potential

Gravel deposits in the Beddington district occur in two settings. The most important type is as terraces along the valleys of the Beddington and Nose Creeks. The second type includes small isolated ice-contact deposits that trend generally northeast-southwest across the district, and an ice marginal ice contact deposit in sections 22, 23, 26, and 27 of 26-1-W5 (figure 5).

Many of the minor eskers contain fine sand with little or no coarse aggregate. There are no data on character or reserves of aggregate in these minor ice contact features.

Shetsen (1981, p. 75) estimated minimum reserves in the terrace gravels along Beddington Creek as 1 500 000 m^3, indicating that the gravel ranged in thickness from 3.0 to 10.5 m, with a mean thickness of 4.0 m. Isolated deposits along the valley of Nose Creek were estimated to contain 75 000 m^3 of gravel, from 2.0 to 4.0 m thick and overlain by 0 to 2.5 m of clay.

Factors affecting land use

The most significant feature of the Beddington district with regard to land use is the shallow depth to bedrock throughout much of the district (Moran, 1986c).

Delacour-Shepard district

Description

The Delacour-Shepard district, the largest district in the Calgary area, encompasses 690 km^2 (270 mi^2), stretching north-south along nearly the entire eastern edge of the study area (figure 1). It extends from the valleys of Nose Creek and the Bow River to the eastern margin of the study area. The district is characterized by a gently undulating to rolling plain composed of till of the Crossfield Formation (figure 5). In the northwest corner of the area, till of the Balzac Formation crops out. In places, till of the Balzac, Lochend, and Spy Hill (lower unit) Formations has been encountered in boreholes (figures 3, cross sections F-F′, G-G′, H-H′, I-I′; and 4, cross sections J-J′, K-K′). The dissected surface of the flat-lying to gently dipping Porcupine Hills Formation has been cut into a series of valleys tributary to the ancestral Bow River (figure 15). The thickness of glacial drift varies from more than 30 m in some of these valleys and in the southwestern part of the district to less than 5 m in other places (figures 3, cross sections F-F′, G-G′, H-H′, I-I′; and 4, cross sections J-J′, K-K′).

Characteristics of stratigraphic units

Till of the Spy Hill Formation has been recognized in seven locations in the Delacour-Shepard district. These sites, which are in valleys cut into the bedrock, are scattered throughout the central and western part of the district (figures 3, cross sections F-F′, G-G′, H-H′, I-I′; 4, cross sections J-J′, K-K′; and 6). They consist of silty clay till with a mean texture of 19-36-45. The carbonate content is the highest in the district with a mean value of 47 mL CO_2/g. The ratios of montmorillonite to kaolinite plus chlorite, and crystalline to carbonate grains in the coarse sand, are the lowest in the district, with values of 0.47 and 0.23, respectively. At four sites, the Spy Hill Formation is overlain by till of the Lochend Formation; at one site, the overlying unit is till of the Balzac Formation, and, at two sites, silt and sand of the Lochend or Balzac Formation overlies the Spy Hill Formation.

Till of the Lochend Formation has been recognized in 14 sites in the district. Most of these locations are in

the northern and central part of the district, with no sites in the west (figures 3, cross sections F-F′, G-G′, H-H′, I-I′; 4, cross sections J-J′, K-K′; and 10). The texture of the till is nearly the same as that of the Spy Hill Formation with a mean texture of 21-36-43. It contains slightly less carbonate (42 mL CO_2/g) and has a higher ratio of montmorillonite to kaolinite plus chlorite (0.66). The ratio of crystalline to carbonate grains in the coarse sand is significantly higher at 1.19.

Till of the Balzac Formation has been recognized at 14 sites in the district, principally in the northern part (figure 11). The till is more silty and sandy than the two underlying units with a mean texture of 26-40-34. The carbonate content and ratio of crystalline to carbonate grains in the coarse sand are intermediate between the values for the underlying units with values of 44 mL CO_2/g and 0.73, respectively. The ratio of montmorillonite to kaolinite plus chlorite is slightly higher than in the Lochend Formation, with a value of 0.75.

Till of the Crossfield Formation, which is the surface material over the entire district (figures 5 and 12), was sampled at 29 boreholes. It contains the most sand and least silt of any of the till units, with a mean texture of 31-32-37. The carbonate content is the lowest (27 mL CO_2/g) and the ratios of montmorillonite to kaolinite plus chlorite, and crystalline to carbonate grains in the coarse sand, are the highest of any unit at 0.87 and 3.41, respectively.

Resource potential

The only gravel deposits in the Delacour-Shepard district are small isolated ice contact deposits, largely eskers, scattered throughout the district (figure 5). Six major groups of eskers occur in the district. The series of eskers in the northeastern corner of the district contains several small pits that have been exploited in the past for local usage. Pits in eskers, and thrust and molded subtill gravel in the northwestern part of the district, just east of Balzac, have also yielded small amounts of gravel. An esker train about 15 km long is mapped in 25-29-W4 in the north-central part of the district (figure 5), but no pits are known in this feature and its composition is uncertain. A second northeast-southwest trending esker complex is mapped in 24-29-W4, extending into 23-29-W4. No exposures were seen in this feature. An esker extends 10 km from the town of Delacour in 19-25-27-W4, along the trough occupied by Chestermere Lake, to 26-24-28-W4. Exposures indicate that this esker contains gravel, but no data are available on the thickness or character of the deposit. Finally, two ice contact deposits occur near the south-central margin of the district. The northern one, in 6-23-28-W4 and 36-22-29-W4, is composed of poorly sorted gravel overlain by till and contorted by glaciotectonic disturbance. The southern deposit, in sections 19 and 30 of 22-28-W4 and 24-22-29-W4, consists of sand. Other minor eskers occur throughout the district and may provide enough gravel for local needs.

Factors affecting land use

The widespread occurrence of saline soils, especially those containing sulfate salts, poses problems of concrete corrosion throughout much of the district. Bedrock is encountered at shallow depths at some locations in the northern part of the district.

Upper Bow valley district

Description

The upper Bow valley district extends along the valley of the Bow River from the western edge of the study area to a line arbitrarily drawn northward from the east edge of Broadcast Hill to the Big Hill upland (figure 1). The district follows the ancestral Bow River valley, most of which has been exhumed and is occupied by the present valley of the Bow River. Remnants of valley fill remain on both sides of the valley along most of its length, although the bedrock valley wall is exposed in numerous places on the north side in the western part of the district (figure 5). In the west, the base of the fill consists of silty lacustrine sediment, which is in turn overlain by clayey lacustrine sediment. Dissected remnants of this lower part of the fill sequence are exposed along the north side of the river in the western part of the district (figure 5).

Characteristics of stratigraphic units

The lower unit of the Spy Hill Formation has been recognized in the lower part of the fill along the access road to Valley Ridge Park (formerly Happy Valley) (figure 8). Here, the lower unit of the Spy Hill Formation, which is exposed at the toe of the slope, consists of 2.5 m of hard gray till containing abundant pink and purple quartzite pebbles; 9.2 m of clayey lacustrine sediment of the Spy Hill Formation overlies this till. Till of the upper unit of the Spy Hill Formation overlies the clay unit and is widespread in the eastern part of the district (figure 3, cross sections D-D′, E-E′). The till is generally clayey and contains more crystalline fragments in the coarse sand fraction than does the till of the lower unit of the formation. Clay of the Calgary Formation conformably overlies the upper till unit of the Spy Hill Formation in sections and boreholes in the eastern part of the district (figure 3, cross sections D-D′, E-E′). At the Valley Ridge Park section, this unit, although partially covered, appears to be sand that is overlain by clay (figures 3, cross sections D-D′, E-E′; and 8). The clayey lake sediment grades westward into silty to very fine sandy lacustrine sediment (figure 3, cross sections D-D′, E-E′). Along the southern edge of the district, between the Trans-Canada Highway and the base of Broadcast Hill, the Calgary Formation consists largely of silt (figure 5). This silty unit, which is well exposed along the Trans-Canada Highway in the extreme eastern part of the district, has been eroded away, farther north in the center of the valley. Deposition of this silty unit at the top of the Calgary Formation marked the end of the filling period of the ancestral Bow River valley.

The fill was largely removed by the Bow River as it eroded to its present level, slightly below the floor of the preglacial valley (figure 3, cross section D-D′). Stages in the down-cutting, which mostly accompanied the retreat of the glacier that deposited the Lochend Formation, are marked by a series of fluvial terraces, which begin as high as the upland surface on the south side of the valley in several places (figure 3,

cross section D-D′), and extend down to present river level. These terraces are generally floored by gravel, which is commonly, though not everywhere, capped with silt. In most places where the terraces intersect the valley wall, they are covered with alluvial fan sediment (figure 5).

Resource potential

Gravel deposits occur along the entire length of the Bow River valley in the district. They range from currently active point bar and mid-channel bars along the Bow River through low terraces just above modern floodplain level, to high terraces inset just below the upland level. Limited areas of gravel at the modern floodplain level near Cochrane contain minimum estimated reserves of 150 000 m^3 of gravel that are as much as 4 m thick and overlain by a discontinuous veneer of silt as much as 1.5 m thick (Shetsen, 1981, p. 76). Low terraces stretching from Cochrane to Bowness in the western part of the City of Calgary contain a minimum of 10 300 000 m^3 of gravel that varies in thickness from 1.0 to 9.5 m and is overlain by a discontinuous silty overburden as much as 2.0 m thick (Shetsen, 1981, pp. 75-77). High terraces along the entire reach of the river contain a minimum of 7 900 000 m^3 of gravel that is 2.0 to 15.0 m thick and is overlain by discontinuous silty sand or clay overburden as much as 5.0 m thick (Shetsen, 1981, pp. 75-76). Shetsen's estimate includes only part of the high terrace deposits, so the total reserves are significantly greater. Well-sorted fine to medium-grained sand occurs on some of the terrace deposits, as along the high terrace from 16-31-24-2W5 to 10-33-24-2W5 along the Trans-Canada Highway just west of Bowness.

A series of alluvial fan deposits along the base of the north edge of the Broadcast Hill upland have produced small amounts of poorly sorted gravel. A similar deposit on the north side of the valley of the Bow River, just west of Cochrane, was described by Shetsen (1981, p. 75) as containing 100 000 m^3 of gravel that was 5.0 to 10.0 m thick.

The fine-grained sand to coarse silt of the Calgary Formation and overlying alluvial fan sediment has been quarried in the Bowness area in 4-34-24-2W5 for use as fill material.

Factors affecting land use

The silty and especially the coarse silty to very fine sandy lacustrine sediment of the Calgary Formation is susceptible to serious rill erosion on steep, unvegetated slopes. This is a potential problem along the entire length of the Bow River valley in the district. In addition, the more clayey sediment that characterizes the formation in the west is susceptible to mass wasting failures. Steep slopes and shallow depth to bedrock is a potential cause of increased construction costs in several areas of the district.

Lower Bow valley district

Description

The lower Bow valley district extends in an arc from the valley of Fish Creek southward and then eastward to the eastern margin of the study area (figure 1). It includes the present valley of the Bow River as well as the area underlain by the ancestral Bow River. Unlike the situation in the upper Bow Valley district, the present Bow River has removed only a small proportion of the fill in the buried valley (figure 5). In the western part of the district, the fill in the valley contains a considerable thickness of silt and sand of lacustrine or fluvial origin interbedded with till (figure 4, cross sections K-K′, N-N′). In the eastern part of the district, nearly the entire thickness of the fill, which is 75 m in places, consists of till (figure 4, cross sections N-N′, Q-Q′).

Characteristics of stratigraphic units

The lowermost unit in the valley fill is gravel. On the basis of borehole data, it appears likely that gravel-floored terraces lie at several different levels separated by as much as 20 m (figure 4, cross section Q-Q′). Overlying the gravel is a discontinuous unit consisting of hard stony till. The stones in this till include an abundance of pink and purple quartzite and other rock types characteristic of a mountain source. The crystalline to carbonate ratio of the very coarse sand fraction is very low (0.12). This basal till, which predates the Spy Hill Formation, is the oldest glacial unit recognized in the study area. It has been recognized in three testholes and sections, in which it is from 2.0 m to 3.0 m thick (figure 2).

Till of the lower unit of the Spy Hill Formation has been recognized in testholes throughout the district. In all 10 testholes, the till is silty clay to clayey silt with a mean texture of 19-40-41. The carbonate content varies from 34 to 60 mL CO_2/g, with a mean of 43. There is a trend toward lower values in the eastern part of the district (figure 16). The ratio of crystalline to carbonate grains in the coarse sand fraction ranges from 0.07 in the west to 1.29 in the east, with a mean value of 0.34. Only three of nine sites have values greater than 0.30, two of which are situated on the extreme eastern edge of the study area (figure 16). Deleting these samples gives a mean of 0.18, which better represents the characteristics of the unit over most of the study area. The ratio of montmorillonite to kaolinite plus chlorite varies from 0.26 to 0.89, with a mean of 0.58. Although the number of sites is substantially less than with other compositional parameters, there appears to be a trend toward higher values of this clay mineral ratio toward the east (figure 16).

Till of the upper unit of the Spy Hill Formation was encountered in five testholes in the western part of the district (figure 7). The till is dominantly silty with a mean texture of 18-47-35. The carbonate content is higher at 48.8 mL CO_2/g, and the ratio of montmorillonite to kaolinite plus chlorite is lower at 0.40, than in the underlying lower unit. The ratio of crystalline to carbonate grains in the coarse sand fraction is 0.24. In the same area, this ratio is 0.10 in the underlying lower unit.

The Lochend Formation makes up most of the valley fill in the district. In the eastern part of the district, till of the formation is as much as 34 m thick (figure 4, cross section N-N′); in the west the formation consists of thin, discontinuous till capping a thick sequence of silt

and sand (figure 4, cross sections K-K′, N-N′). The texture of the till is generally consistent, with a mean of 23-37-40. At three sites, a variable, sandier, less clayey facies, with a mean texture of 38-36-26, is included in the formation. In the western part of the district, the till is substantially thinner and less sandy and clayey than in other parts of the district. The till of the Lochend Formation is recognized by its high to moderately high ratio of crystalline to carbonate grains in the coarse sand fraction. The ratio ranges from 0.68 to 3.79 with a significant increase toward the eastern part of the district (figures 7 and 17). Seven sites in the

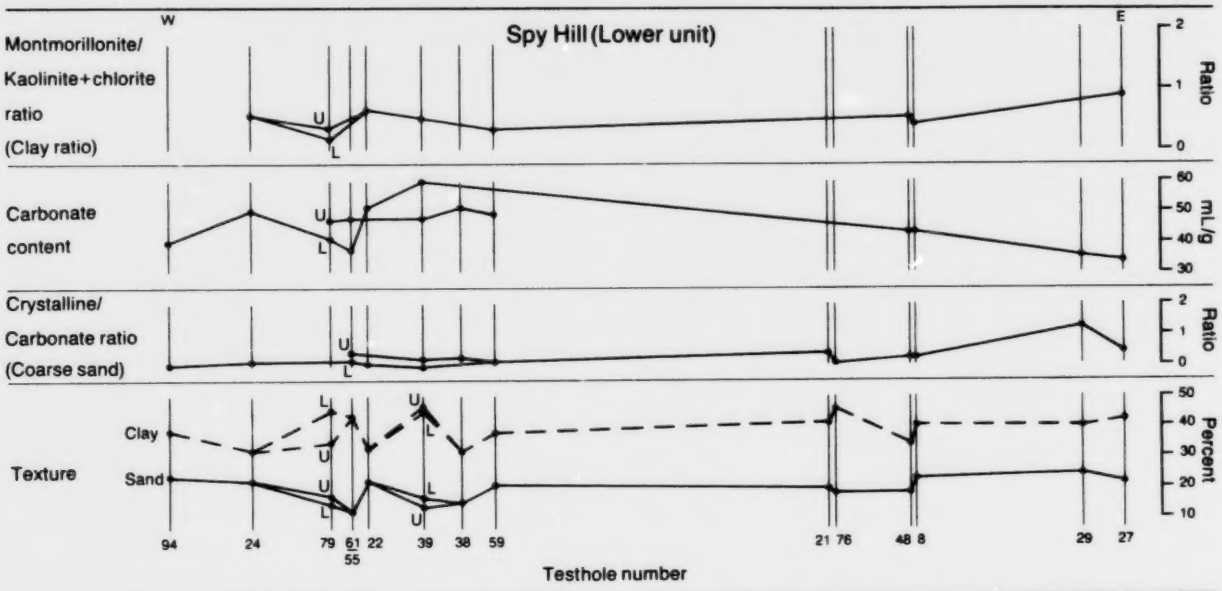


Figure 16. Compositional variation in till of the Spy Hill Formation from east to west in the lower Bow valley district

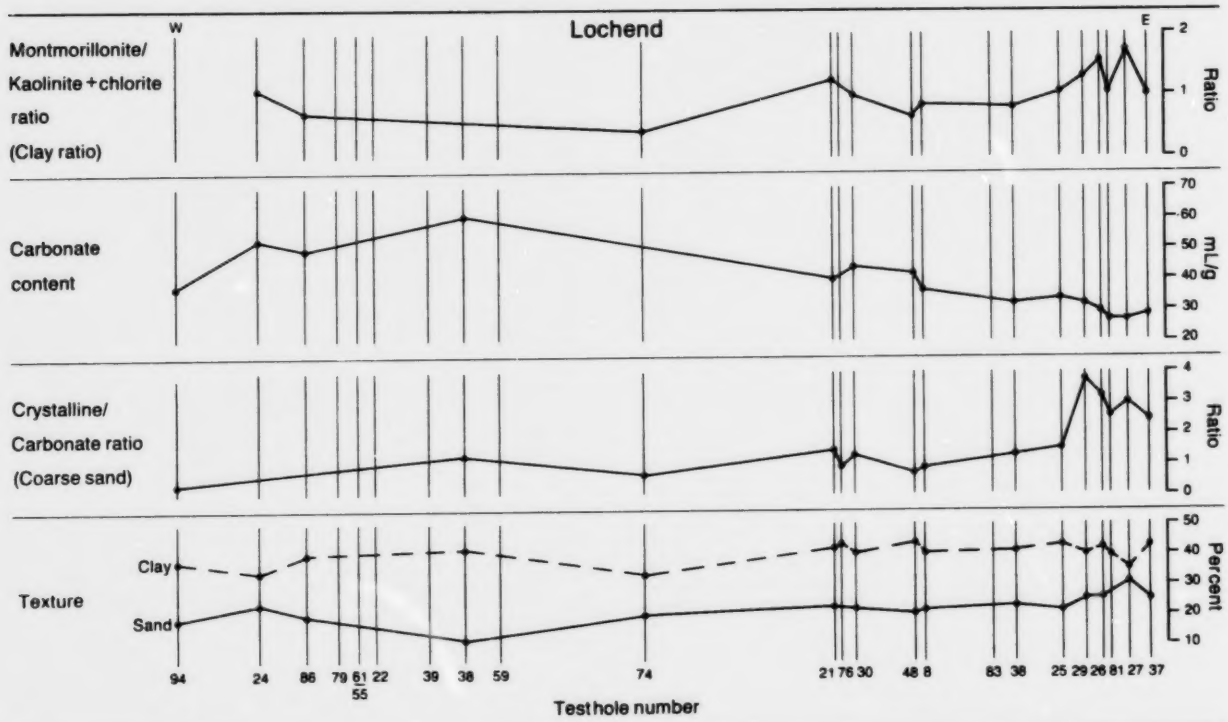


Figure 17. Compositional variations in till of the Lochend Formation from east to west in the lower Bow valley district

west and central part of the district have a mean value of 1.04, whereas seven sites in the east have a mean value of 2.58. The carbonate content of the till is generally low in the east and increases to the west (figure 17). It ranges from 26 to 44 mL CO_2/g, with a mean of 33.9 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite ranges from 0.42 to 1.70, with a mean of 1.03. In this ratio, there is also a tendency toward a decrease moving from east to west (figure 17).

Till of the Balzac Formation is recognized in the eastern part of the district by the ratio of crystalline to carbonate grains in the coarse sand, which is lower than in the overlying and underlying units. In the western part of the district the till is absent. The till grades westward into a thick sequence of silt to very fine sand (figure 4, cross section N-N'). Till of the Balzac Formation is texturally more variable than in other units. Two main textural groupings are present. The most common, which is represented by 11 sites, is a silty clayey till with a mean of 23-40-37. The second group, from five sites in the west and central part of the district, is a silty sandy till with a mean texture of 34-42-24. These two textural groups differ slightly in other compositional parameters as well. The first and more common group contains less carbonate (37 mL CO_2/g vs. 47 mL CO_2/g) and has higher ratios of montmorillonite to kaolinite plus chlorite (1.05 vs. 0.80) and crystalline to carbonate grains in the coarse sand (1.24 vs. 0.66) than does the sandier, less common group. The larger group is substantially more variable in all these mineralogical parameters than is the sandier till. As in the underlying Lochend Formation, part of this variation is the result of substantially higher values of both clay mineral and coarse sand ratios in samples from the extreme eastern part of the district (figure 18).

The Crossfield Formation is the uppermost till unit throughout the district, although in the western part of the district, this unit is somewhat difficult to recognize with confidence. The till of the Crossfield Formation has a very consistent texture, except in a small area south of Midnapore in the western part of the district. At 16 sites the mean composition is 30-34-36. The till in these sites generally has a low matrix carbonate content that ranges from 20 to 37 mL CO_2/g, with a mean of 27 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite is generally high, with a range from 0.83 to 2.05 and a mean of 1.23. The ratio of crystalline to carbonate grains in the coarse sand fraction ranges from 2.56 to 6.25, with a mean of 4.32. Only 2 of 16 sites have values lower than 3.0.

At four of five of the testholes in the western part of the district, the composition of the till in the Crossfield Formation is atypical of the remainder of the unit (figure 19). In this area, the sand content of the till is substantially lower, ranging from 15 to 24 percent. The clay content is highly variable, ranging from 26 to 45 percent, and the silt content averages about 10 percent higher than is typical for the unit elsewhere in the district; the mean texture is 19-44-37. The carbonate content is high for the unit, with a mean of 55 mL CO_2/g. The ratio of montmorillonite to kaolinite plus chlorite is 0.50, which is very low for the Crossfield Formation. The ratio of carbonate to crystalline grains in the coarse sand is similarly low, with a mean value of 2.40.

Resource potential

The major gravel resource within the district consists of floodplain and terrace deposits along the Bow River. Smaller deposits occur along meltwater channels that cross the upland south and west of the Bow River.

Shetsen (1981, pp. 62,72) estimates minimum reserves of the terraces along the Bow River as 34 600 000 m³ of gravel that range in thickness from 2.1 to at least 7.5 m and are overlain by discontinuous silty to sandy overburden that is as much as 3.0 m thick. Gravel deposits occur here along the channel at the western edge of the district, south of Midnapore (figure 5), and along the channel that trends southeast from the Bow River valley in the northeast quarter of 2-22-29W4 (figure 5). Shetsen (1981) estimated minimum reserves of the deposits at the north end of the latter channel as 250 000 m³ (p. 63); the gravel is at least 2 m thick and crops out at the surface. A small sand deposit at the upland surface just south of the Bow Valley in 12-22-29W4 and 7-22-28W4 contains a minimum of 1 500 000 m³ of sand that is at least 3 m thick. Extensive areas of the district are underlain by sand (figure 5), and some of this material may be of commercial significance for fill.

The largest gravel deposit in the district is the basal gravel on the floor of the valley of the ancestral Bow River. This gravel underlies the entire district except

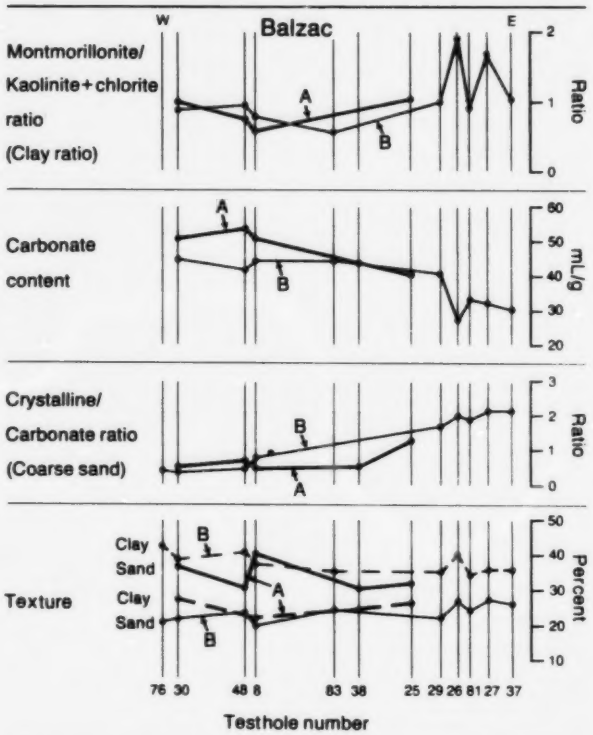


Figure 18. Compositional variation in till of the Balzac Formation from east to west in the lower Bow valley district

where it has been removed by the modern Bow River. It generally has a maximum thickness of about 10 m and is overlain by 25 to 70 m of till, and silt and clay. Because of the depth of burial, its most likely value is as an aquifer; however, at some date in the future, rising costs of aggregate may make limited exploitation of the gravel along outcrops in the Bow River valley economically desirable.

Factors affecting land use

Bedrock is close enough to the surface to be encountered in shallow excavations in several places along the southeastern edge of the district and along the valley of Pine Creek in the southwest.

The steep slopes along the valley of the Bow River are potentially susceptible to mass wasting failures. This is especially true where silty to sandy lacustrine or fluvial sediment crops out beneath till. This type of instability is a problem along the entire eastern valley wall in 12-22-29W4. The mechanism appears to be related to spring sapping at the base of the permeable sediment. Discharging groundwater causes piping of the fine-grained sand, which undermines the slope, promoting rotational sliding above the seep. The slide material obstructs further discharge, resulting in increased pore pressure and recurrent, progressive sliding. A failure of this type occurred in 1981 along the Burnco access road in 9-22-29W4.

The coarse silt to very fine sand of the Calgary Formation on the Midnapore flat in 22-1W5 (figure 5) is susceptible to severe rill erosion where exposed on unvegetated slopes.

Calgary city district

Description

This district encompasses the core area of the city of Calgary (figure 1). The southern boundary is the valley of Fish Creek. The eastern boundary is the eastern valley side of the Bow River and, farther north, of Nose Creek. In the east, the northern boundary is drawn arbitrarily at McKnight Boulevard, which roughly corresponds to the northern limit of silty lacustrine sediment of the Calgary Formation. Farther west, this boundary is drawn at the base of Nose Hill, roughly following John Laurie Drive. The western boundary of the district is the east end of Broadcast Hill, approximately along Sarcee Trail, and includes lines drawn arbitrarily across the Bow and Elbow River valleys to the north and south, respectively (figure 5), and the east end of the Sarcee upland district.

The amount of information available on the geology of this district is highly variable from place to place. In the older residential parts of the city, borehole and outcrop data are almost totally absent. A series of ten boreholes drilled by Geological Survey of Canada dur-

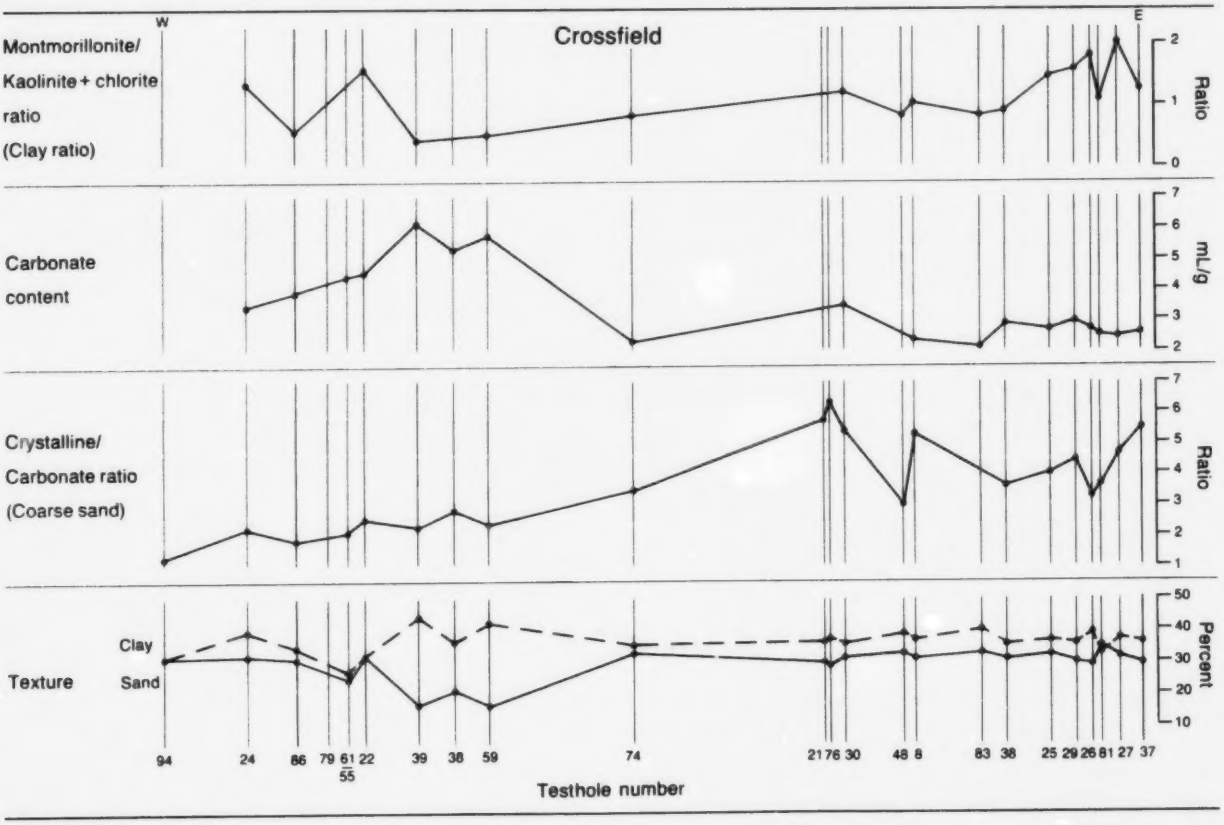


Figure 19. Compositional variation in till of the Crossfield Formation from east to west in the lower Bow valley district

ing 1967 and 1968, augmented by about ten holes drilled as part of this study, provide most of the basis for evaluating the subsurface geology. An additional set of several thousand engineering test borings are available, but most of these are either too shallow or the lithologic descriptions are too obscure to permit geological interpretations to be drawn. Engineering reports for a number of highway and sewer projects, as well as some subdivision projects, for which subsurface investigations have been carried out during the past ten years have augmented the data base. These borings have proved invaluable in developing a detailed understanding of stratigraphic relationships. Construction in the city has commonly involved cuts and fills of as much as 3 to 5 m of material, because of the amount of local relief in much of the district. As a consequence, original terrain has been largely destroyed or obscured; thus, shallow excavations and borings reveal little of the original geology. Because of abrupt changes in thickness and lithologic character of fill material, it was not considered practical nor especially meaningful to attempt to map the fill. Rather, the original geology of much of the district was mapped using a set of aerial photographs taken in 1949 when the city was much smaller. This interpretation was verified and modified on a selective basis, using the higher quality subsurface data described above.

In general terms, the geology of the district is characterized by three areas having roughly uniform geologic conditions:

- North of the Bow River the surface is underlain by a thick succession of lacustrine silt or silty sand to sandy silt of the Calgary Formation (figure 5). Till of the Lochend Formation underlies the silt or lies within the succession, and is generally not recognized because of its high clay content. Till of the Spy Hill Formation overlies bedrock or gravel of the Empress Formation.
- The valleys of the Bow and Elbow Rivers, and a series of roughly north-south trending ice marginal meltwater channels are floored by gravel, which in places is capped by silt (figure 5).
- The upland areas south and west of the Bow River are generally bedrock cored and overlain by till of the Lochend or Crossfield Formations (figure 5). Over much of the district, the till is capped by a veneer of silty sand to sandy silt of the Calgary Formation, which is generally less than 2 m thick. In places, especially along ice marginal ridges at the limits of individual till units, the till is exposed at the surface. Bedrock outcrops are generally restricted to steep valley sides along the Bow and Elbow Rivers.

Characteristics of stratigraphic units

Limited data are available on which to base any understanding of the stratigraphy of till units within the Calgary city district. Till of the Spy Hill Formation (lower unit) is present throughout the district. It overlies the rock, or, in the base of preglacial valleys, rests on gravel (figure 2). Till of the Lochend Formation has also been recognized throughout the district, where it rests on till of the Spy Hill Formation or lacustrine silt of the Lochend Formation, as at site 77-23 (figure 4, cross sections L-L′, M-M′). Till of the Balzac Formation is present only along the northeastern edge of the district, where it overlies a thick sequence of silt and sand and is directly overlain by till of the Crossfield Formation. Along the eastern edge of the district, till of the Crossfield Formation is the surface unit or underlies silt or sand (figure 5).

Resource potential

Gravel deposits are common throughout the district (figure 5). In nearly every case, however, they have been extensively exploited or have been built over to the point where they no longer constitute a resource that can be developed.

Factors affecting land use

Coarse gravel and hard bedrock constitute impediments to excavation throughout the district. The distribution of areas of thin drift and gravel are shown by Moran (1986a, 1986c).

Thick lacustrine silt and clay units are susceptible to erosion and mass wasting failures along steep slopes such as the valley sides of major rivers in the city area. Mass wasting along the valley of the Bow River has been a recurring problem within the city. Most of the slides, though not all, occur where the river is actively undercutting the bank. Some occur where thin drift veneers the bedrock slope and simply slides off. Others occur by backward rotation of large slump blocks in thick sequences of lacustrine sediment or till. These types of slides recur as the river removes the material at the toe of the slide.

Quaternary history and chronology

Initial late Wisconsinan glaciation

The earliest advance of late Wisconsinan ice into the Calgary area was by a glacier flowing out of the Rocky Mountains by way of the Bow River valley. This glacier, which deposited the till of the lower unit of the Spy Hill Formation, flowed eastward along the Bow River valley to at least the eastern edge of the study area (figure 6). To the northeast of Calgary, the till of this advance is present as much as 8 km east of the 5th Meridian (figure 6). To the north, the glacier overtopped the Big Hill upland and flowed at least as far as Beddington Creek (figure 6). Largely on the basis of morphological evidence, Jackson (1977, 1980) concluded that this glacier encountered the continental ice sheet and was forced to flow southward along the mountain front. Jackson (1980, p. 462; 1977, p. 161) indicates that this

southward flow of the glacier extended no farther than the Highwood River, about 40 km south of the western edge of the study area.

The flow of ice from the mountains decreased, causing the glacier that deposited the lower unit of the Spy Hill Formation to begin wasting. As this occurred, the continental glacier expanded westward across the Calgary area. The maximum extent of this advance is in the Cochrane area in the north and along the west side of the Priddis valley district in the south (figure 20). This glacier deposited till of the upper unit of the Spy Hill Formation (figure 7).

In some areas, the mountain glacier had completely wasted prior to the advance from the east. On the Big Hill upland east and north of Cochrane, for example, the topography strongly suggests that there was no stagnant ice beyond the limit of the upper unit of the Spy Hill Formation. Along the Bow River valley west of Calgary, lake sediment between the upper and lower units of the Spy Hill Formation (figure 8) clearly shows that the valley was ice free during the advance of the glacier from the east.

Over much of the area, however, the continental glacier overrode stagnant, wasting ice of the mountain glacier from the west. The presence of stagnant ice beyond the westernmost limit of the continental ice sheet at the time of its maximum advance is one of the most important lines of evidence supporting the near synchroneity of the mountain and continental advances. The evidence for such a relationship is found in the foothills area west of the Priddis valley district. Here, clayey lake sediment with hummocky topography lies between several of the foothills ridges (Moran, 1986a). The topography indicates that the sediment was deposited on stagnant ice. Because of the slope in this area, the presence of a lake here requires that a dam of glacier ice be present to the east and south. Because the mountain glacier was retreating to the northwest, the most logical glacier to provide such a dam was the continental ice sheet.

Retreat from maximum eastern advance

As the continental glacier began to waste from the area, the lake in the foothills in the southwestern corner of the area dropped in elevation from as high as 1340 m (4400 ft) to 1295 m (4250 ft), as successively lower outlets were opened by wasting of the glacier to the south of the study area (figure 20).

Retreat stage I

As the lake lowered further, it was restricted to the Priddis valley. It was separated from a higher lake in the Elbow River valley west of the study area. This higher lake drained into Lake Priddis initially by a spillway along Priddis Creek (figure 21). The Priddis Creek spillway was abandoned, as two lower spillways at an elevation of about 1250 m (4100 ft) north of the town of Priddis were opened by continued wasting of the ice eastward in the Elbow River valley (figure 21). To the north, in the valley of the Bow River, a lake lay to the west of the ice margin at Cochrane. Drainage from the margin of the continental glacier farther to the north crossed the Big Hill upland by the Big Hill Creek meltwater channel and emptied into the lake at Cochrane, depositing sand (figure 21).

Retreat stage II

Further wasting of the ice allowed Lake Priddis to drop to about 1205 m (3950 ft) and expand eastward into the valley of Fish Creek (figure 22). Exposure of a lower outlet, now occupied by Six Mile Coulee through the Sarcee Reserve, resulted in abandonment of the short-lived spillways north of Priddis. The lake in the valley of the Elbow River coalesced with the lake in the valley of the Bow River at about 1220 m (4000 ft) as the stagnant ice in the Springbank district wasted (figure 22). The Big Hill Creek meltwater channel eroded its valley deeper and deposited a gravel fan at its mouth at Cochrane. Slack-water clay was deposited over the sand north of Cochrane, as the locus of deposition of coarse sediment shifted southward. A series of supraglacial and ice-walled lakes formed on the Big Hill upland. Drainage from these lakes flowed southward to the lake in the Bow valley by a series of rivers flowing in tunnels beneath stagnant ice (figure 22).

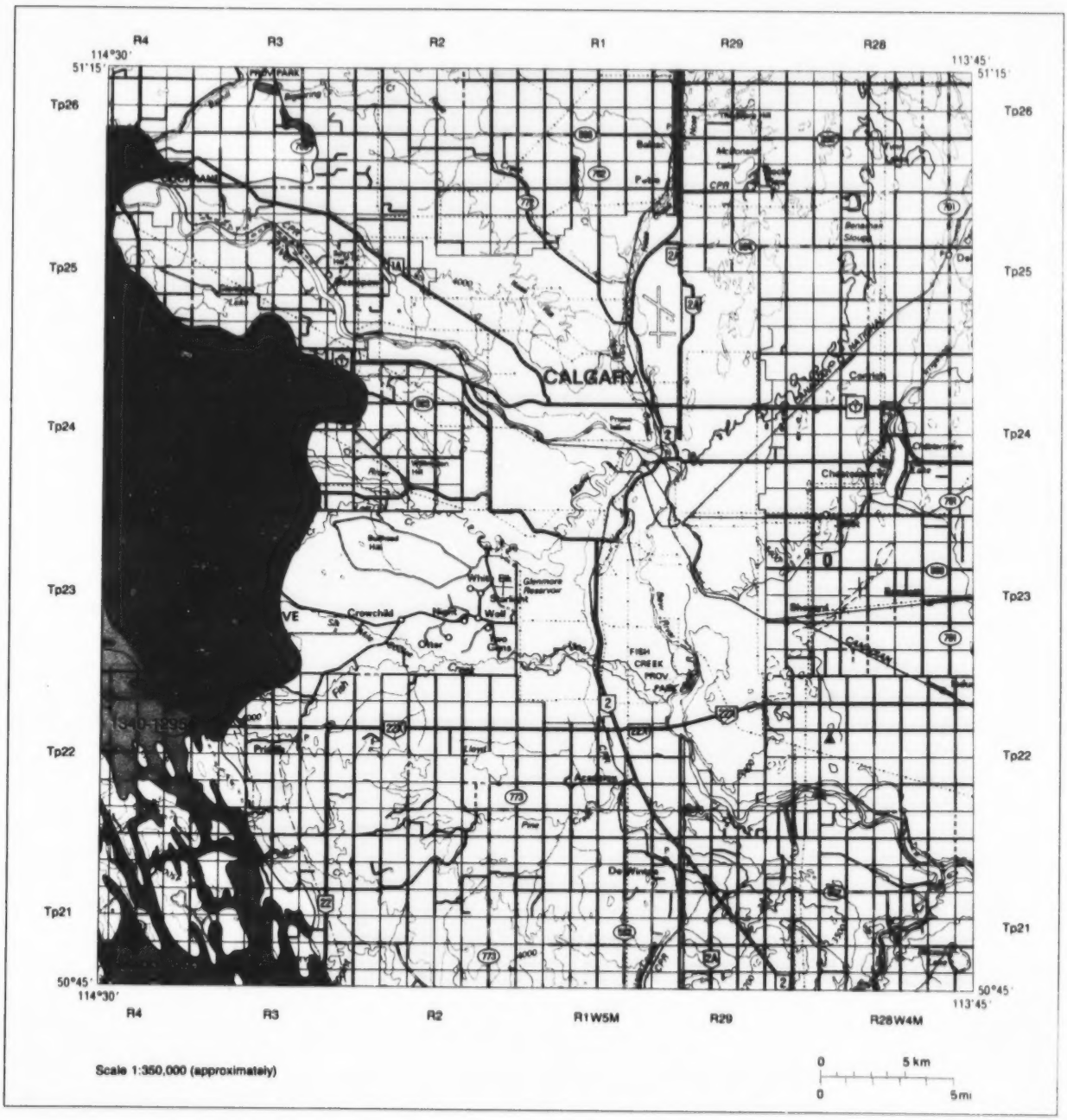
Retreat stage III

Further wasting of the glacier to the east opened lower outlets for the ice-marginal lakes, allowing them to drop until four restricted lakes confined to the valleys of the Bow and Elbow Rivers and Fish and Sheep Creeks were formed; a fifth lake developed in the upper reaches of Pine Creek (figure 23).

The lake in the valley of the Bow River stretched from Cochrane to about the western edge of the city of Calgary. It was fed at the west end by flow from the Bow River and the Big Hill Creek meltwater channel, which joined at the head of the lake. On the north side of the lake, a series of rivers flowed across the Big Hill upland from the still somewhat vigorous ice north of the upland and from ice-walled lakes in the stagnant ice terrain on the upland surface. Major gravel fans were built at the lake edge where these rivers entered the standing water (figure 23).

The lake in the valley of the Bow River drained into the valley of the Elbow River by a small spillway west of Broadcast Hill when the lake levels were above about 1180 m (3875 ft). Where this spillway entered the lake in the valley of the Elbow River, a deposit of gravel and sand formed. The lake continued to drain via the Six Mile Coulee spillway into the valley of Fish Creek, until the spillway was eroded to about 1175 m (3850 ft). The lake in the Fish Creek valley extended southeastward to the area of Lloyd Lake and westward into the north end of the Priddis valley (figure 23). The lake drained southward by way of Pothole Creek when the lake level was higher than about 1185 m (3880 ft), and then through two lower spillways south of Lloyd Lake, which were opened by further ice retreat.

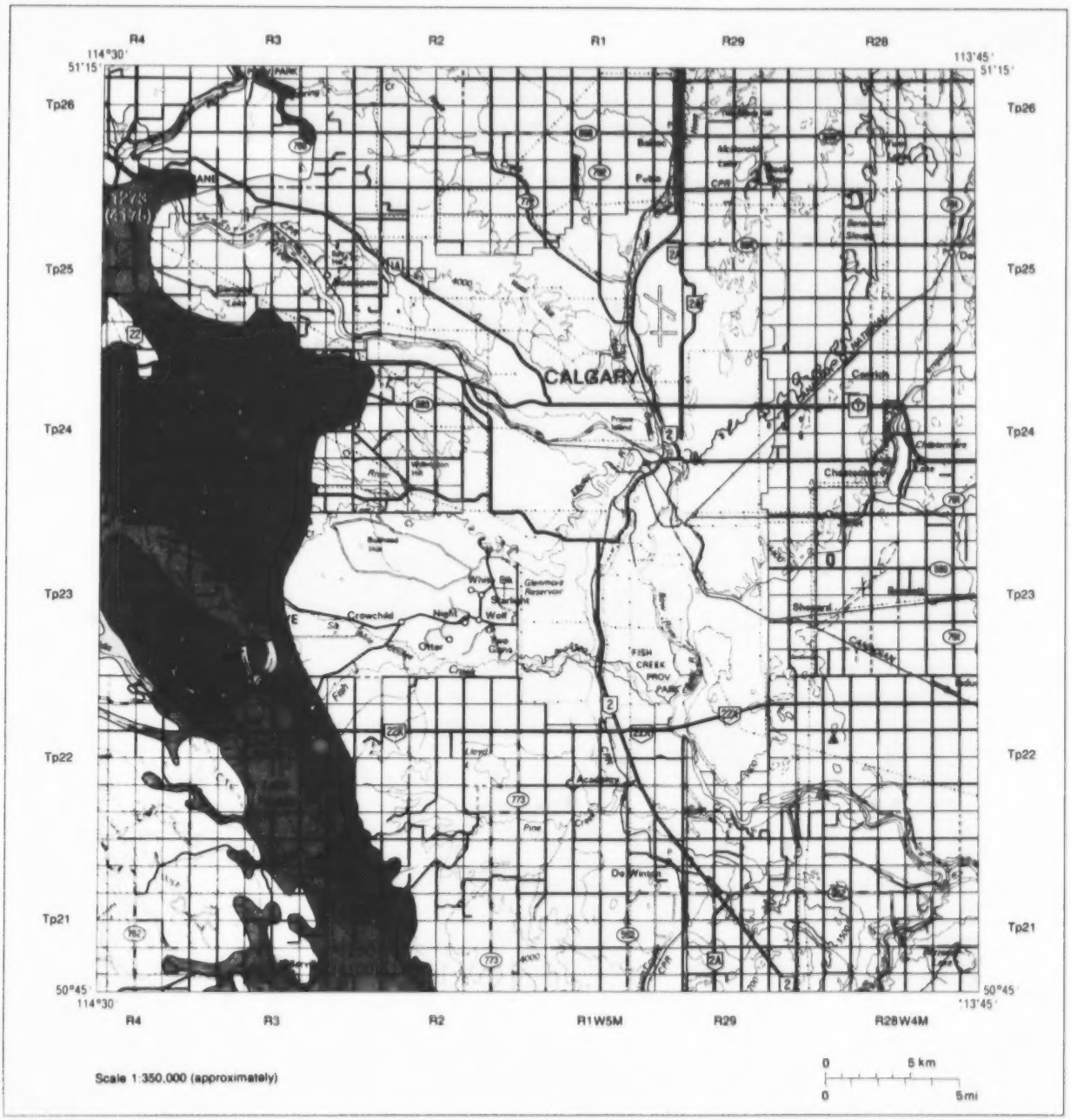
The lake in the upper part of the Pine Creek valley came into existence when the glacier melted to below about 1190 m (3900 ft). It initially drained into the lower part of the Wilson Coulee meltwater channel over a divide at about 1185 m (3880 ft) (figure 23).



Legend

- Minor streams, commonly subglacial, showing flow direction
- Major rivers, channel sediment is generally coarse gravel, arrow shows flow direction
- Preserved remnants of channel sediment
- Shallow lakes, estuaries and deltas, sedimentation generally from traction load.
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3905) Level of controlling outlet of lake in metres (feet)

Figure 20. Maximum advance of the glacier that deposited the upper unit of the Spy Hill and Lochend Formations



Legend

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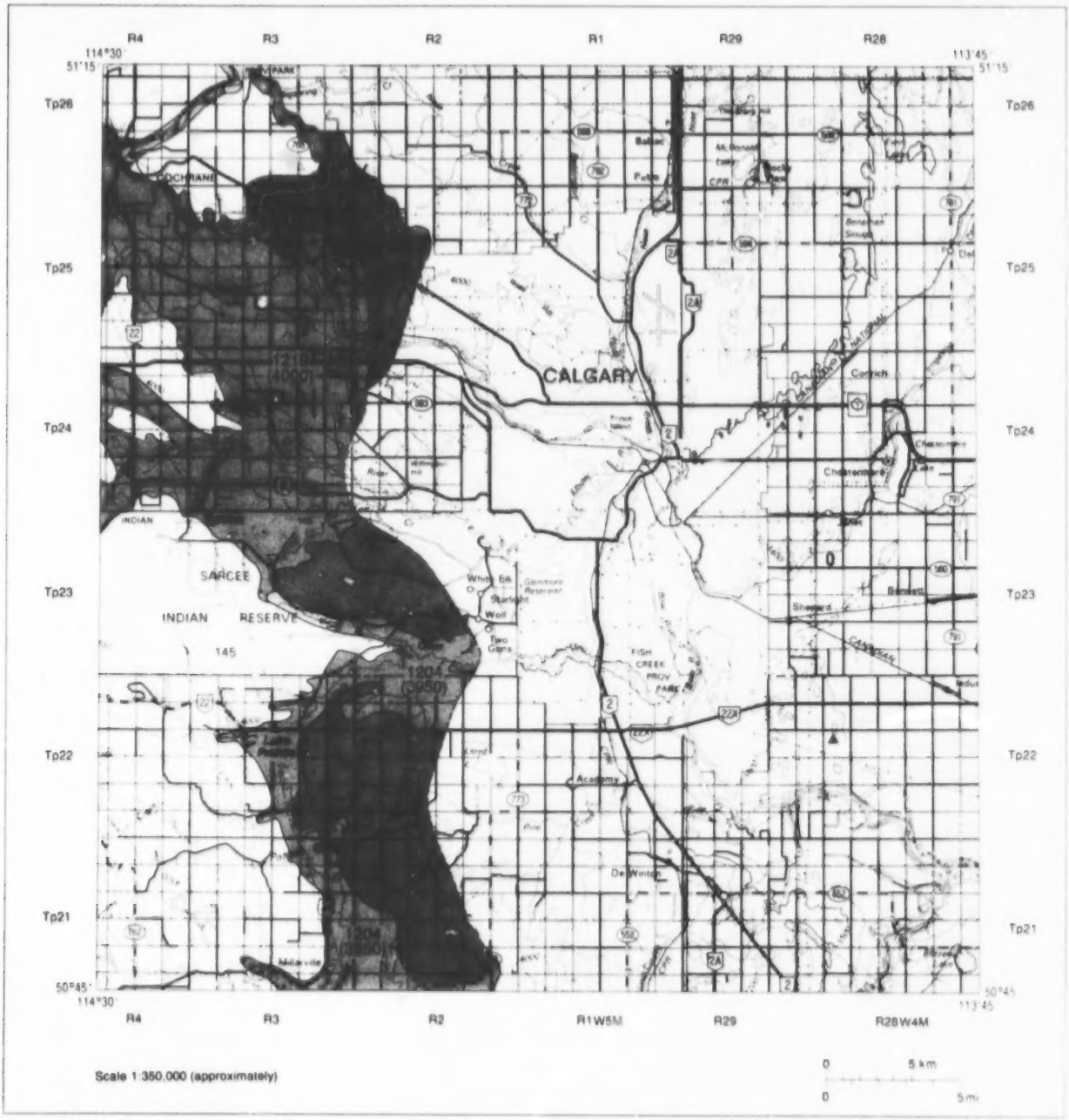
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 21. The first stage in the wastage of the initial late Wisconsinan glacier from the Calgary area



Legend

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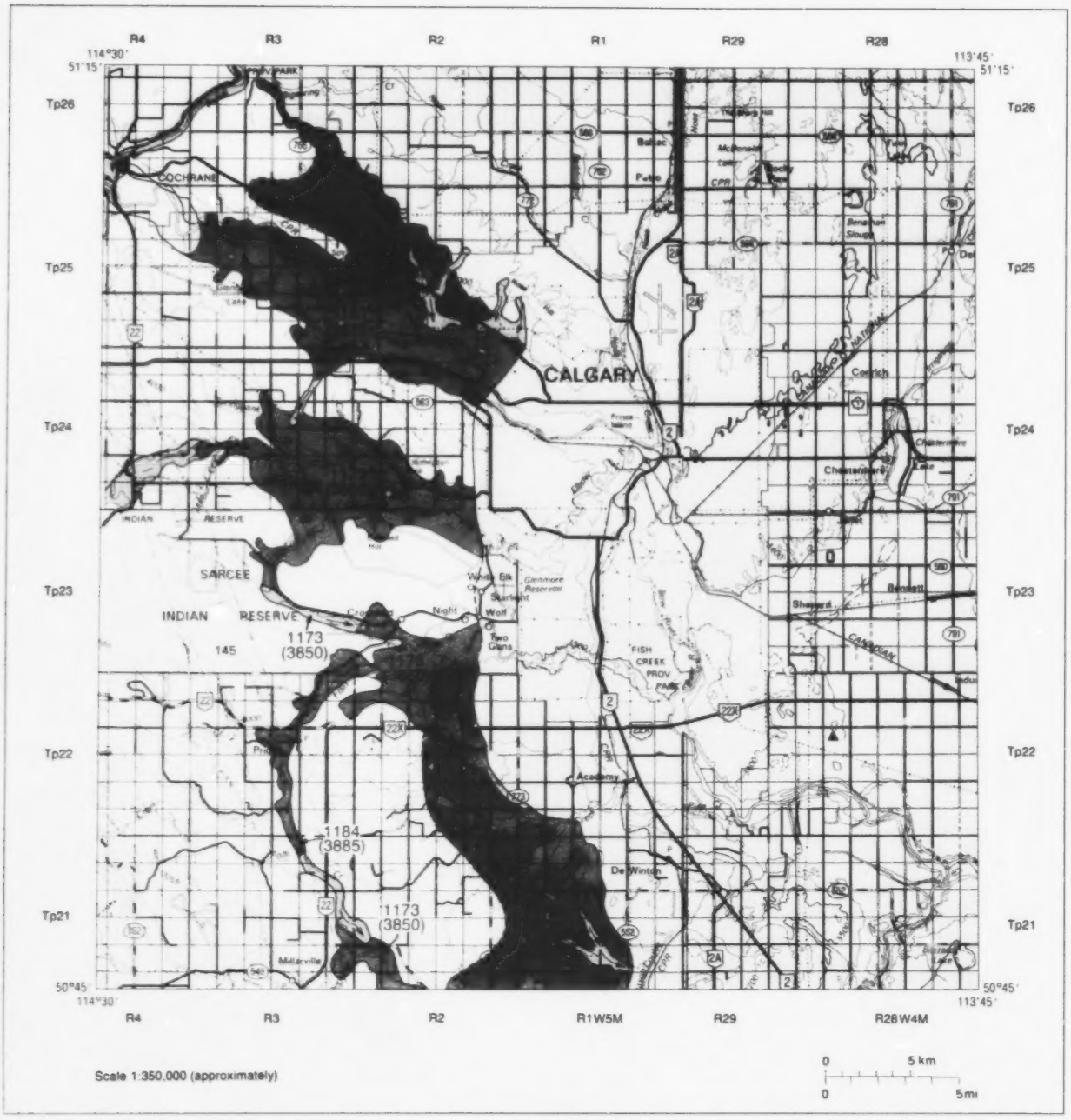
- Preserved remnants of channel sediment
- Shallow lakes, estuaries and deltas, sedimentation generally from traction load.
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 22. The second stage in the wastage of the initial late Wisconsinan glacier from the Calgary area



Legend

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- Preserved remnants of channel sediment
- Shallow lakes, estuaries and deltas, sedimentation generally from traction load.
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 23. The third stage in the wastage of the initial late Wisconsinan glacier from the Calgary area

Retreat stage IV
As the lake in the Pine Creek valley expanded eastward following the wasting ice, a lower spillway just east of the 1185 m (3880 ft) level was opened (figure 24). This outlet was eroded to about 1145 m (3755 ft) before being abandoned. Flow southward from the Lloyd Lake-Fish Creek basin continued via the two spillways just south of Lloyd Lake until they were cut to about 1140 m (3740 ft).

The Six Mile Coulee spillway linking the lake in the Elbow valley to the lake in the Fish Creek basin was abandoned when a tunnel beneath the ice opened along the eastern end of the Sarcee upland (figure 24). The gravel deposit at the east end of the Sarcee Reserve was formed where the hydraulic jump between supercritical flow in the tunnel became subcritical upon entering the lake (figure 25). This outlet allowed the lake in the valley of the Elbow River to drop to a level of 1150 m (3775 ft).

The spillway across the Springbank district was abandoned in favor of the Sarcee Trail spillway at the east end of the Broadcast Hill upland. This spillway allowed the lake in the valley of the Bow River to drop to about 1160 m (3800 ft) (figure 24). Small remnants of gravel-capped surfaces on both the north and south side of the Bow River between Cochrane and Calgary indicate that the Bow River entered the lake just north of the present site of Springbank Airport (figure 24).

Retreat stage V
The 1145 m (3755 ft) spillway from the valley of Pine Creek into the lower Wilson Coulee was abandoned in favor of a lower outlet into the upper part of the Wilson Coulee spillway at the town of DeWinton (figure 26). This outlet allowed the lake to drain to a level of about 1112 m (3650 ft). Figure 26 shows the sequence of lakes and spillways connecting them to this DeWinton outlet. In the valley of the Bow River, the major gravel deposits of the terrace south and west of Bowness and on the north side of the Bow River at the Bearspaw dam were deposited by the Bow River flowing into the lake at this level, which was about 1128 m (3700 ft).

Retreat stage VI
Renewed retreat of the ice front caused abandonment of the Wilson Coulee spillway in favor of a lower outlet into the lake in the Highwood River drainage at a level of about 1065 m (3500 ft) (figure 27). This river system drained from a lake in the Elbow River valley to the Highwood River with only one very small temporary lake in the Pine Creek drainage (figure 27). The lake in the Elbow River valley extended northward to join a small remnant lake in the valley of the Bow River.

Retreat stage VII
The next stage of the wastage of this glacier from the Calgary area involved disintegration of the ice mass in the lower Bow valley district. The remaining lake dropped by a series of anastomosing channels into the present valley of the Bow River. The details of this final disintegration are not clear, because they were obscured by the ensuing readvance of the glacier that deposited the Lochend Formation. Prior to this advance, the lake in the Bow River valley stood at about 1055 m (3460 ft) and drained southward by way of the Highwood-Little Bow spillway south of the study area (figure 28).

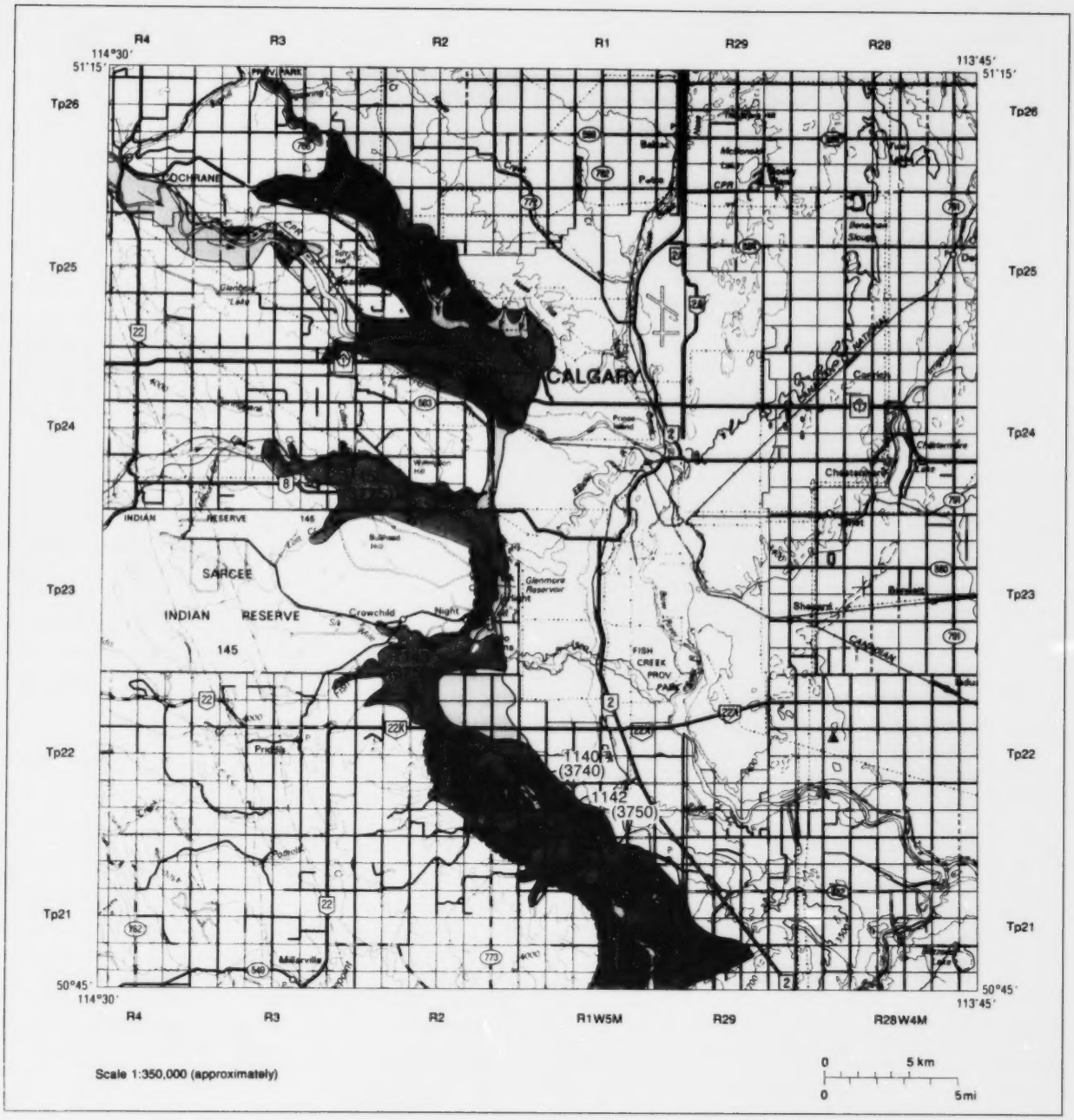
Lochend readvance
Reactivation of the glacier produced a readvance across the area. This advance deposited a discontinuous, thin layer of till of the Lochend Formation over the silty lacustrine sediment in the valley of the Bow River, in the southern part of the area. The ice margin readvanced onto the Big Hill upland in the northern part of the area, increasing the water levels in the ice marginal lakes (figure 29). Outlets from the lake in the Bow River valley below the Sarcee Trail spillway were blocked, forcing the lake to refill to 1160 m (3800 ft). The drowning of the lower part of the Bow River valley caused coarse silt and sand to be deposited over fluvial gravel west and north of Bowness.

The ice wasted rapidly from this margin in the central part of the area, opening lower outlets and allowing the lakes in the Bow and Elbow River valleys to coalesce at 1097 m (3600 ft) (figure 27). Rapid wasting of the ice north of the Big Hill upland was accompanied by the formation of Beddington Creek and expansion of the major lake into the valleys of lower Beddington and Nose Creeks (figure 30).

The final retreat of the ice involved disintegration of the ice in a similar way to that preceding the Lochend readvance. The glacier wasted to the northeast, and the lake in the valley of the Bow River completely drained from the Calgary area. Neither the distance of this retreat nor its duration is known. If active ice remained in Alberta, it was many kilometres northeast of the Calgary area.

Final late Wisconsinan glaciation
The initial pulse of the final advance of late Wisconsinan ice into the Calgary area is represented by the till of the Balzac Formation. As shown by a large number of flutes and drumlins in the Balzac area, north of the city of Calgary, this glacier advanced into the Calgary area from the northeast. The composition of the till, however, is strongly indicative of a source in the Rocky Mountains to the west. The most likely explanation is that glaciers flowing out of valleys to the north, most likely the valleys of the North Saskatchewan and Red Deer Rivers, were diverted southward and then back toward the west by the advancing continental glacier. On the north side of the Big Hill upland, this glacier advanced nearly to the limit of the Lochend Formation (figure 31). Farther to the south, the limit of this advance is largely conjectural as it has been overridden by the glacier that deposited the Crossfield Formation.

In the northern part of the area, this glacier overrode the silty lacustrine sediment that was deposited along the valley of Nose Creek. East of the town of Balzac, till, bedrock, and silty lacustrine sediment has been involved in complex glaciotectonic disturbance. Blocks have been plucked loose from the substrate where the glacier was frozen to its bed, and transported more or less intact as far as 1 km. In other places, the glacier bed was thawed and the blocks have been molded and



Legend

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- Shallow lakes, estuaries and deltas, sedimentation generally from traction load.
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 24. The fourth stage in the wastage of the initial late Wisconsinan glacier from the Calgary area

streamlined into flutes and drumlins where the glacier slid over its bed (figures 32 and 33).

On the basis of the distribution of the till of the Balzac Formation and an extensive deposit of sand and silt on the upland east of the Bow River valley south of Calgary (figures 4 and 31), it is evident that the advancing glacier blocked eastward flow of the Bow River in the southeastern part of the study area as well as farther east to reform the lake at about 1055 m (3460 ft). The lake extended southward into the Highwood River valley and probably drained via the Little Bow River valley, just as it had prior to the final pulse of the glacier that deposited the Lochend Formation.

The continental glacier continued to advance toward the southwest and deposited till of the Crossfield Formation over the area covered by mountain-derived ice, in the area south of Nose Hill. It appears likely that the glacier that deposited the Balzac Formation north of the Big Hill upland had already begun to waste by the time the continental glacier reached its maximum limit. This advance raised the level of the dam confining a lake in the Bow River valley until the lake stood at about 1080 m (3550 ft) (figure 34). The "Beddington Delta", a large gravel deposit at the confluence of Beddington Creek and Nose Creek, was deposited at this time by meltwater derived from the margin of the continental glacier north of the study area. This stage of "Lake Calgary" drained southward along the ice margin, utilizing channels previously cut during retreat of the earlier late-Wisconsinan glacier and emptied into a lake in the Highwood River valley.

As the glacier began to waste from this maximum position, the lake and outlet streams covered the snout of the wasting ice mass with gravel, sand, and coarse silt, and cut a series of channels across the area between valleys of the Elbow and Highwood Rivers. Till of the Crossfield Formation in this area is generally overlain by lacustrine or fluvial sediment; however, in places along the margin, the ice containing the till per-

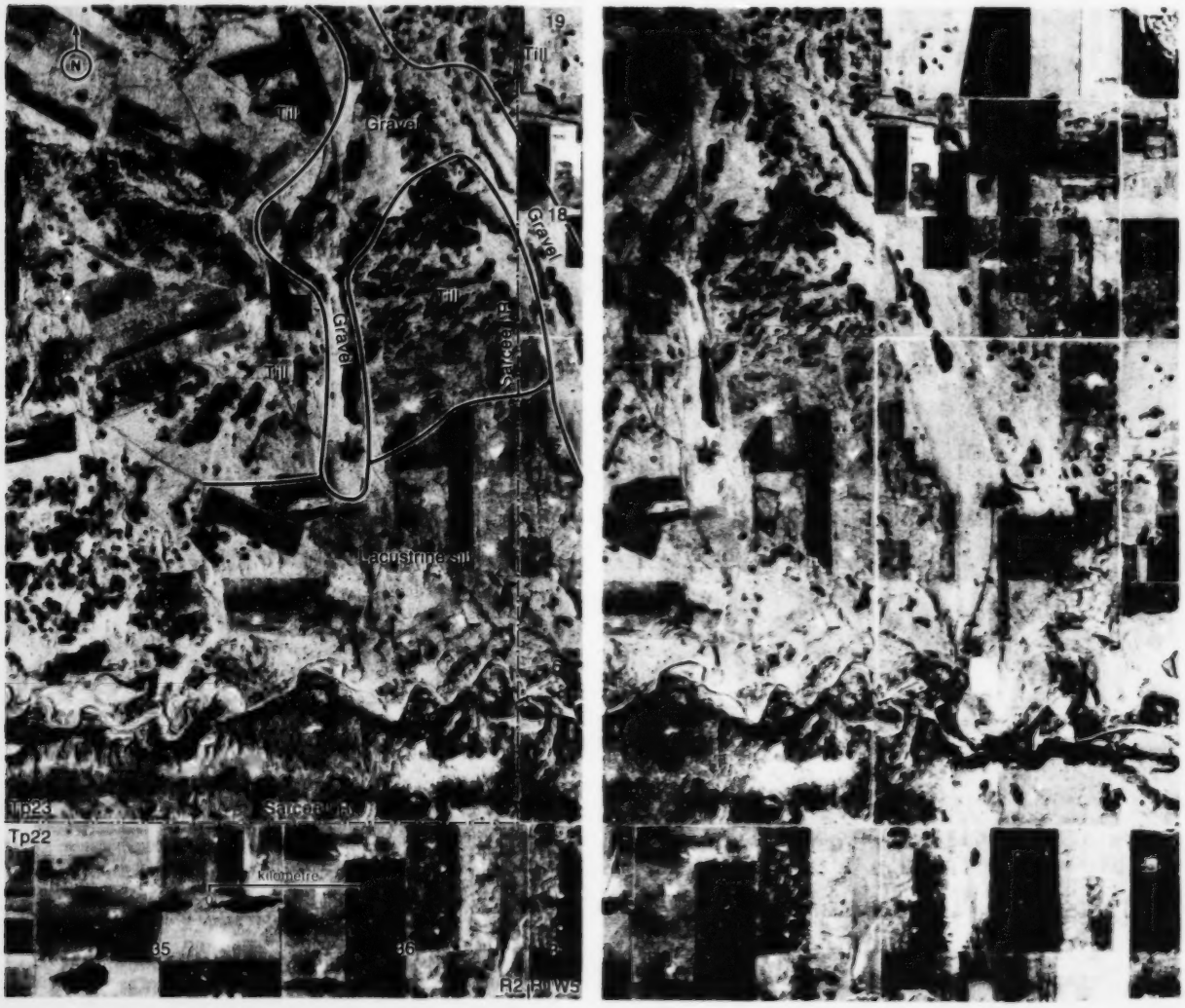
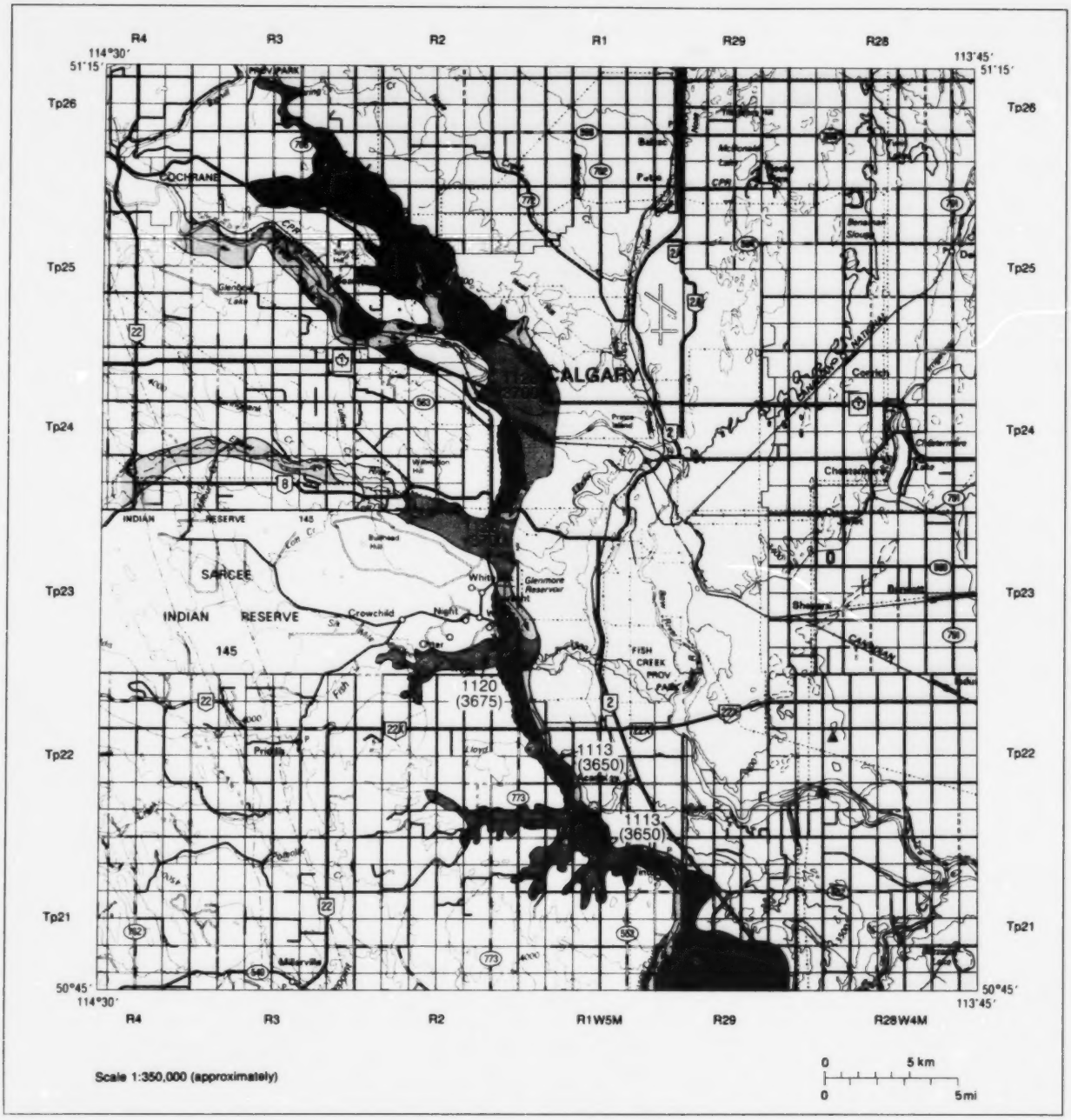


Figure 25. Aerial photographic stereo-pair showing the gravel deposit at the mouth of subglacial tunnel at the east end of the Sarcee Reserve



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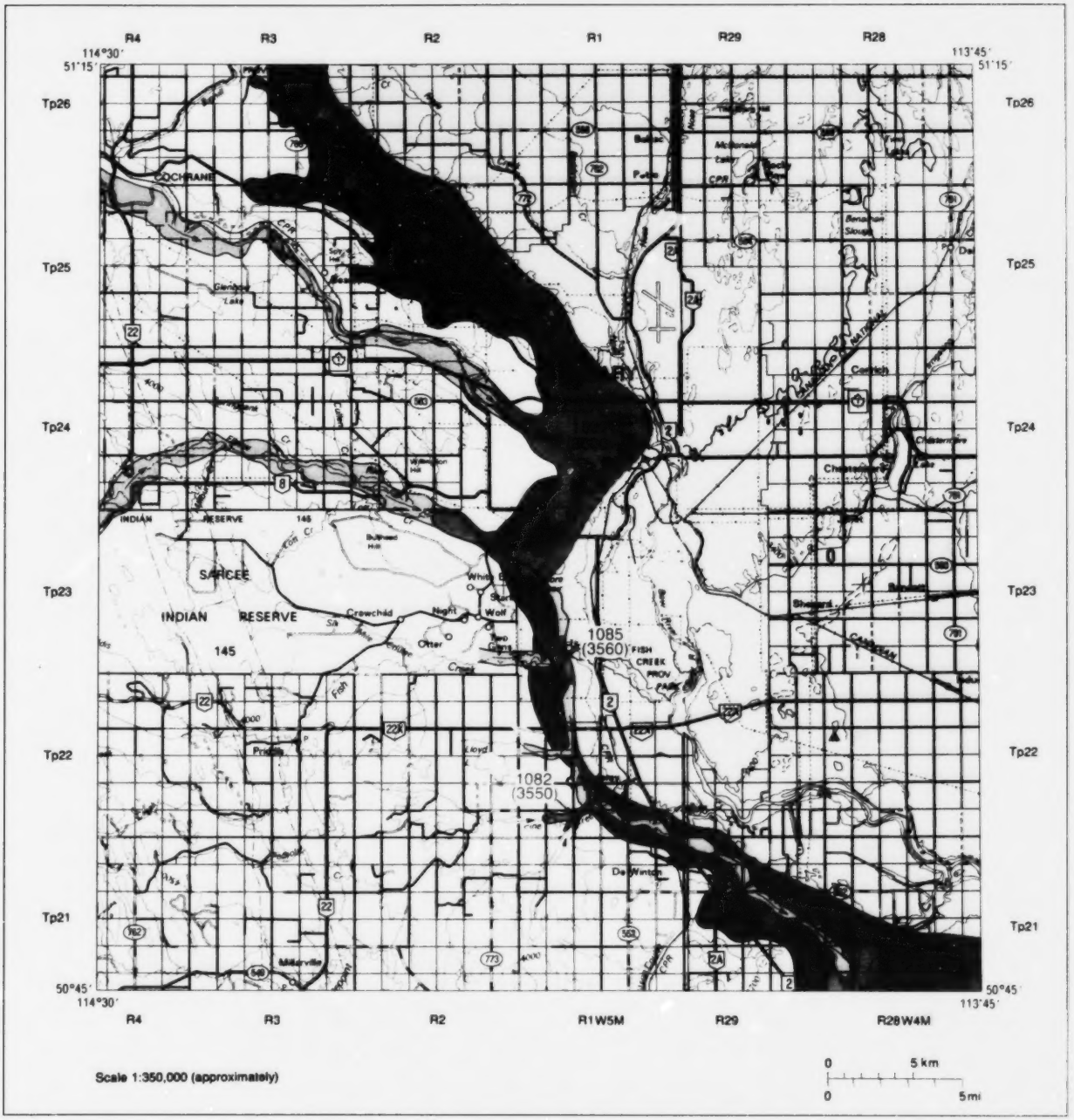
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 26. The fifth stage in the wastage of the initial late Wisconsinan glacier from the Calgary area



Legend

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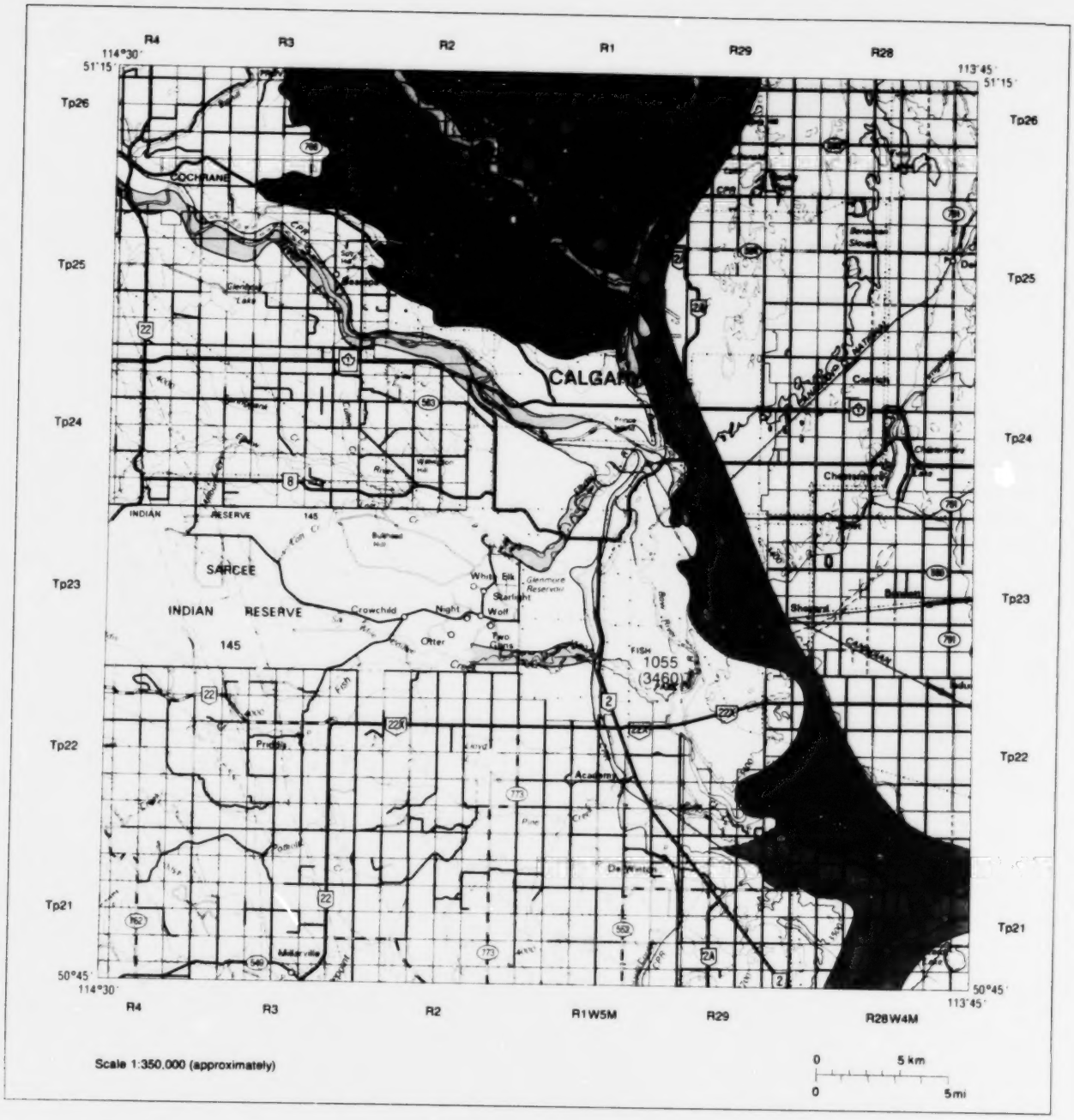
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 27. The sixth stage in the wastage of the initial late Wisconsinan glacier from the Calgary area



Legend

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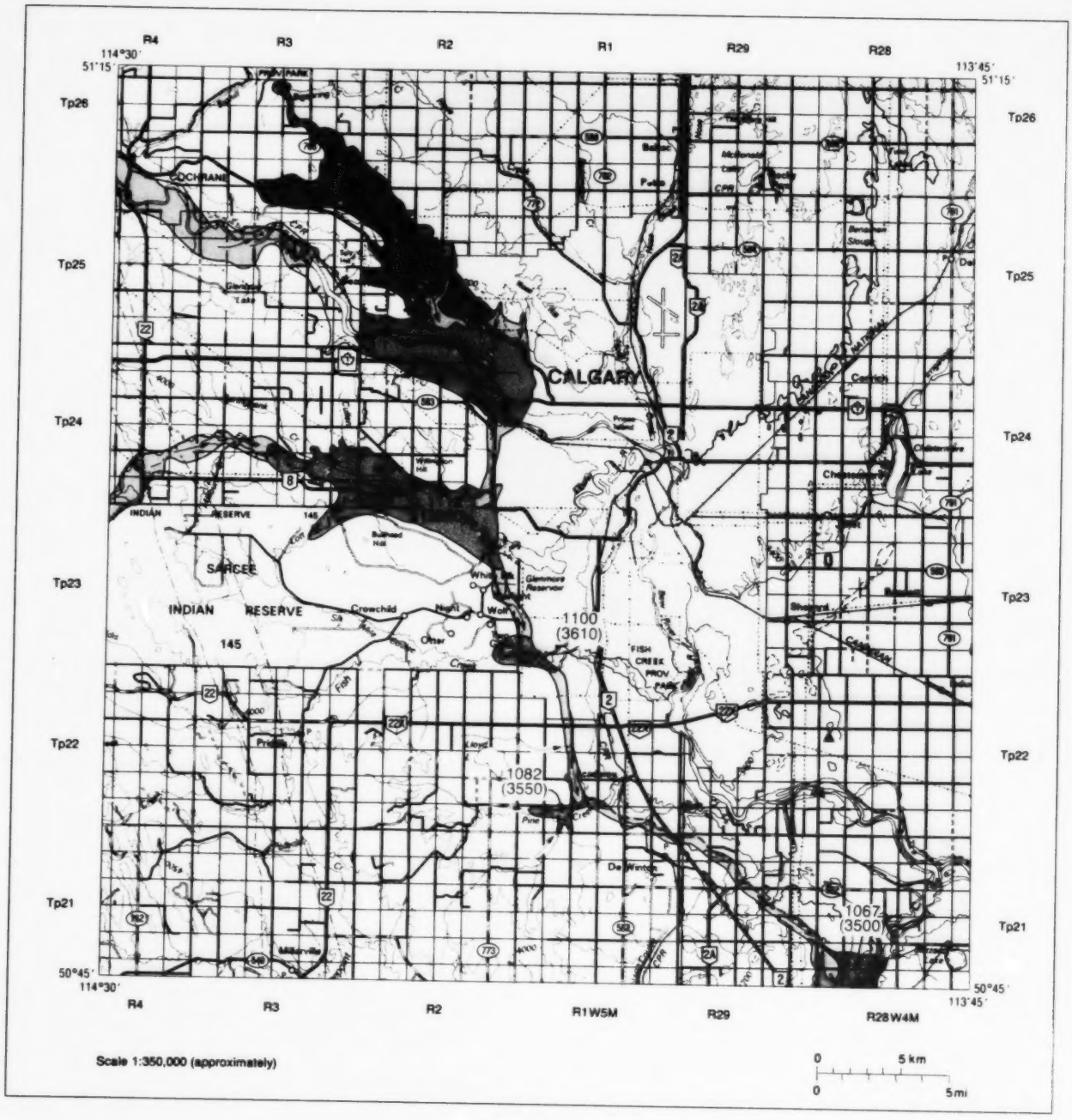
- Deep lake, sedimentation generally from suspended load
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 28. The position of glacial ice and glacier margin lakes prior to the Lochend readvance, the final pulse of advance of the initial late Wisconsinan glacier



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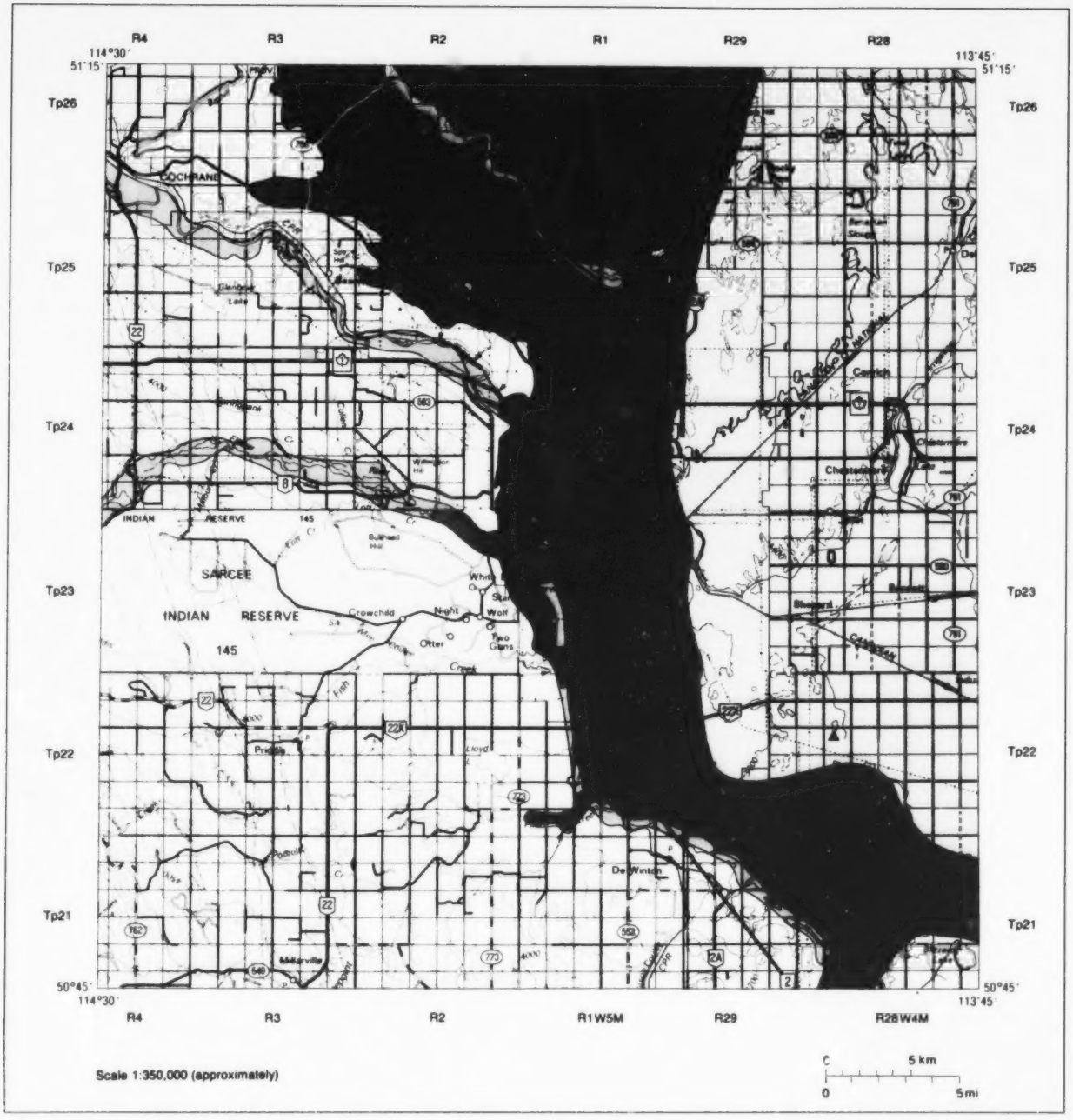
- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 29. Position of glacier margin and ice marginal drainage features at the maximum limit of the Lochend readvance



Legend

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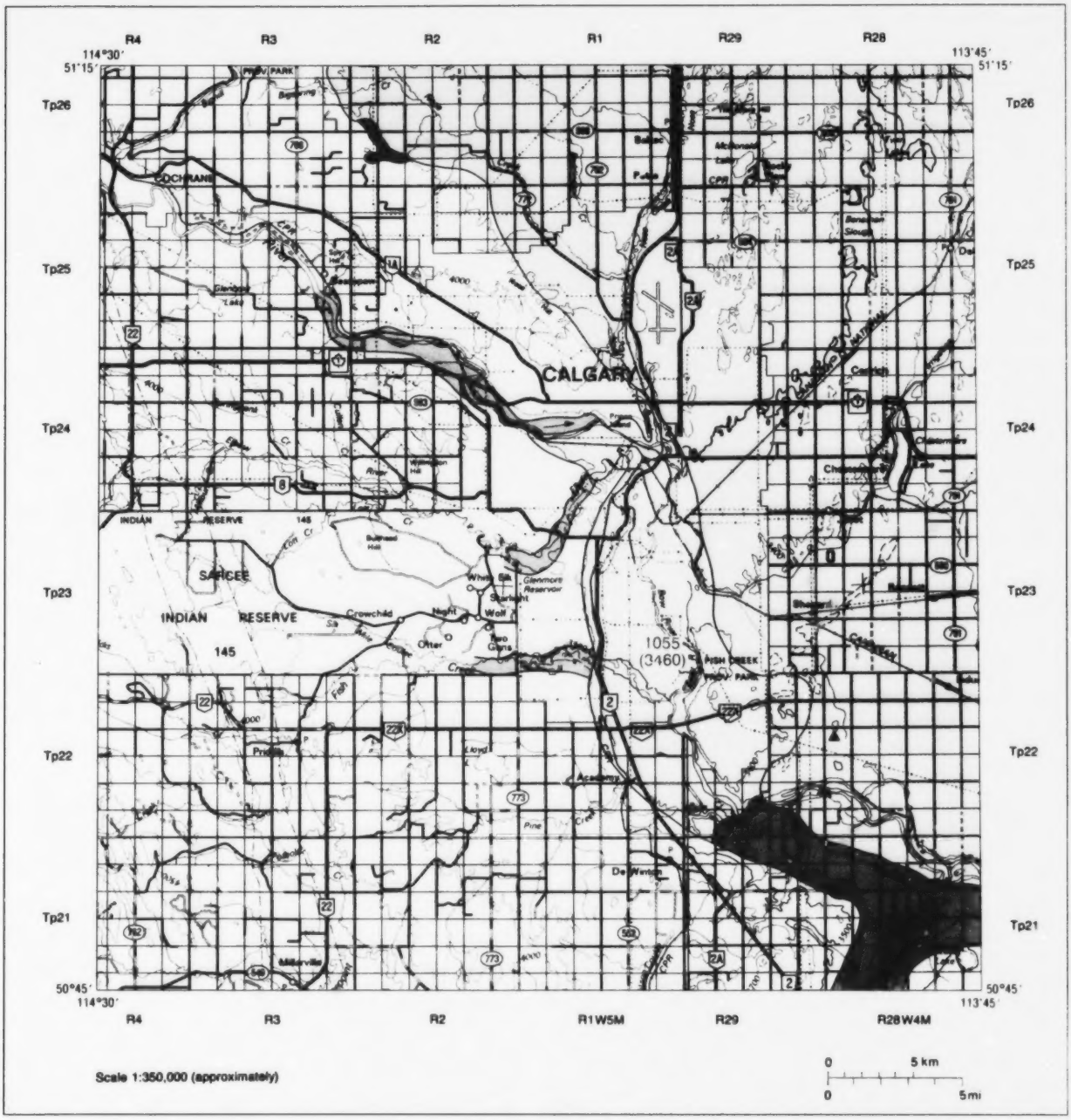
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 30. Ice marginal drainage features during the second phase of retreat from the maximum limit of the Lochend readvance



Legend

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- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 31. The distribution of glacial ice and ice marginal lakes during the maximum advance of the glacier that deposited the Balzac Formation in the Calgary area

sisted until after meltwater deposition had shifted to the northeast where till is now exposed at the surface.

The glacial advance that deposited the Crossfield Formation was the most recent glacial event to affect the Calgary area. Glaciers continued to be active in Alberta east and north of the area for several thousand years following retreat of ice from Calgary.

In the ensuing period, an extensive layer of wind-blown silt—loess—was deposited on the plain to the east and north of the Bow River south of the city of Calgary (figure 5).

Chronology

In the preceding discussion, all the surface sediment in the area is treated as being of late Wisconsinan age. This interpretation is summarized in figure 35. An alternative interpretation has been presented by Stalker (1977) and Jackson (1980, 1983) who argued that the Crossfield Formation is late Wisconsinan and all the other till units are early Wisconsinan or older. The evidence base on which this difference in interpretation hinges is very sparse and is not compelling either way.

Jackson's most recent statement of the case (1983) cites a series of eight radiocarbon dates throughout southern Alberta as supporting the pre-late Wisconsinan age of the till units mapped in this report as Lochend and Spy Hill Formations. All but one of these dates can be discounted as having no bearing on the case, either because of uncertain stratigraphic setting, potential for contamination, or both (Moran and Clayton, 1983). The one date that cannot readily be discounted is from wood that was collected at Midnapore just south of Calgary.

The stratigraphic relations are complex in the area where the Midnapore wood sample, which was dated at 49 400 ± 1000 (GSC-2409), was found. The wood sample was probably collected from within till of the Lochend Formation, which here overlies a 3 to 20 m thick lacustrine sequence, which in turn rests on the Spy Hill Formation (figure 4).

The Crossfield Formation is universally accepted as being of late Wisconsinan age (Stalker, 1977; Jackson, 1980; Clayton and Moran, 1982). The age of the Balzac Formation is less certainly known, but it seems reasonable to conclude that it too is late Wisconsinan. This assignment is based on the assumption that the continental ice that deflected the glacier that deposited the Balzac Formation into the Calgary area was the glacier that deposited the Crossfield Formation. Thus these two units can be separated in age by no more than a few hundred years.

The evidence for the age of the contemporaneous Lochend and Spy Hill Formations is contradictory. There is no stratigraphic evidence of a major unconformity in the succession. If the Midnapore wood date is accepted at face value, this earlier advance of continental ice would be dated as mid-Wisconsinan. If this is so, the Midnapore date is the first evidence of an extensive continent-wide glaciation during the mid-Wisconsinan. All other evidence indicates ice-free conditions throughout the prairies at this time (Fenton, 1984). The possibility that older wood was incorporated into a younger glacier would appear to be the least disruptive to the existing data base but it is not an especially satisfying explanation. Perhaps the best solution to the Midnapore date is to follow the suggestion of Stalker (Lowdon and Blake, 1978, p. 7) to record

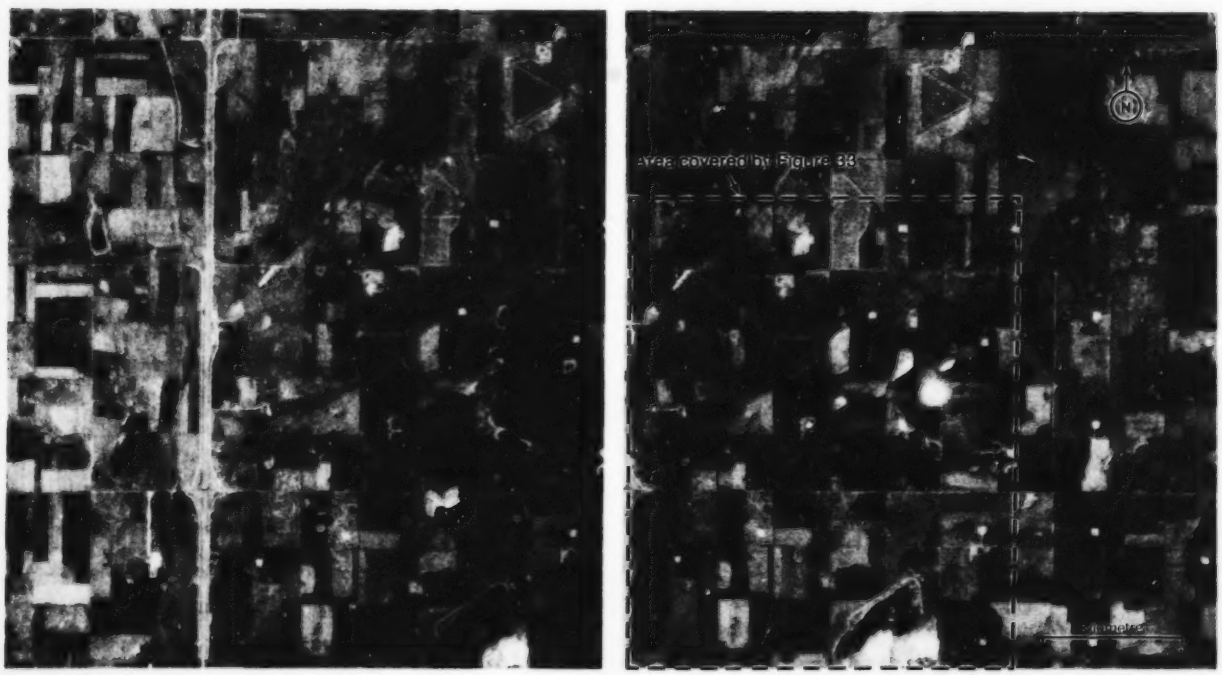
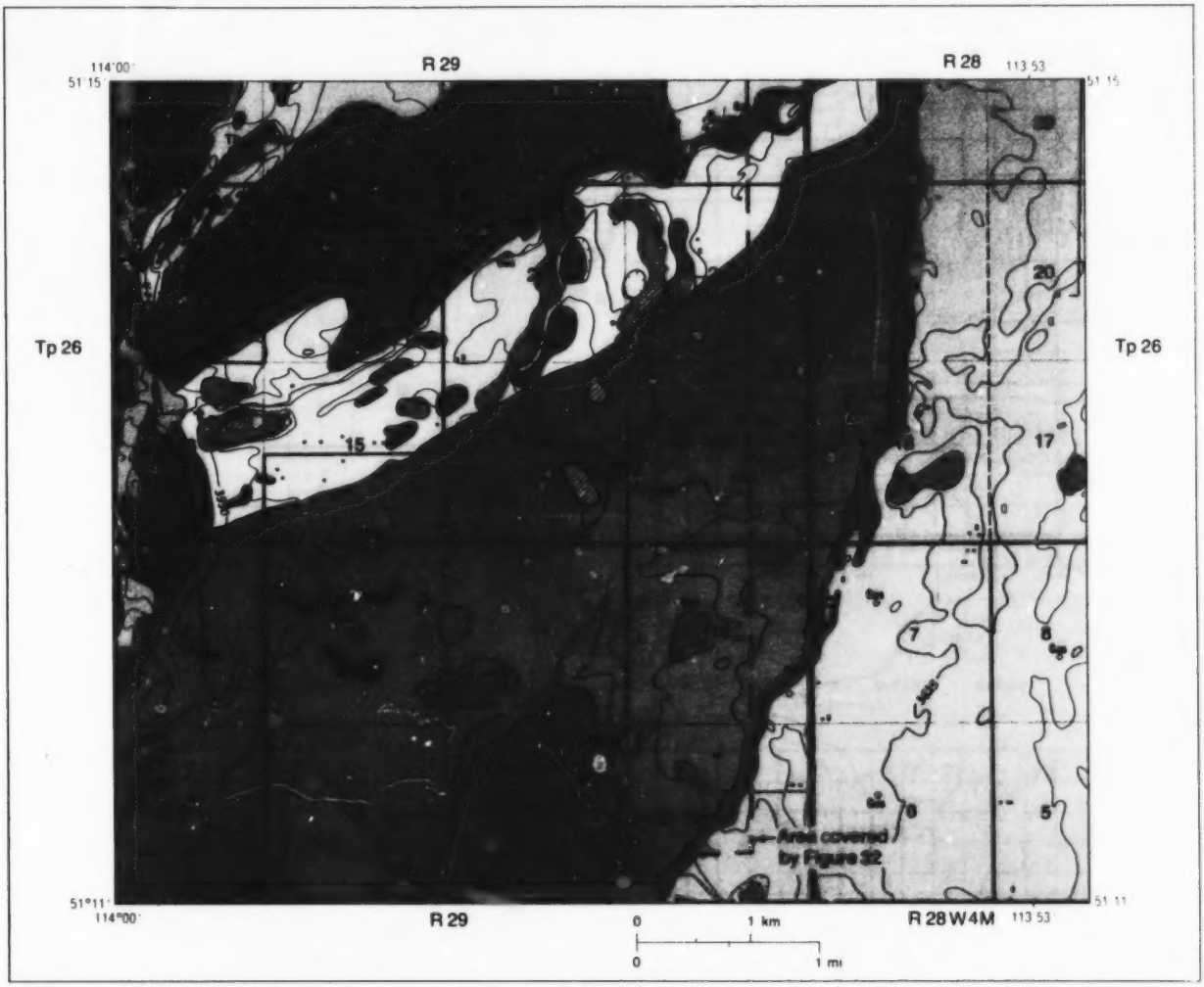


Figure 32. Aerial photographic stereo-pair showing subglacial thrust and streamlined terrain in the Balzac area north of Calgary



Legend

Crossfield Formation

- Sloughs (only larger ones mapped)
- Overbank alluvium (includes alluvial fans)
- Ice contact sand and gravel
- Low to medium relief stagnation moraine
- Ice marginal ridge - end moraine
- Till of Balzac Formation and alluvium draped over bedrock

Balzac Formation

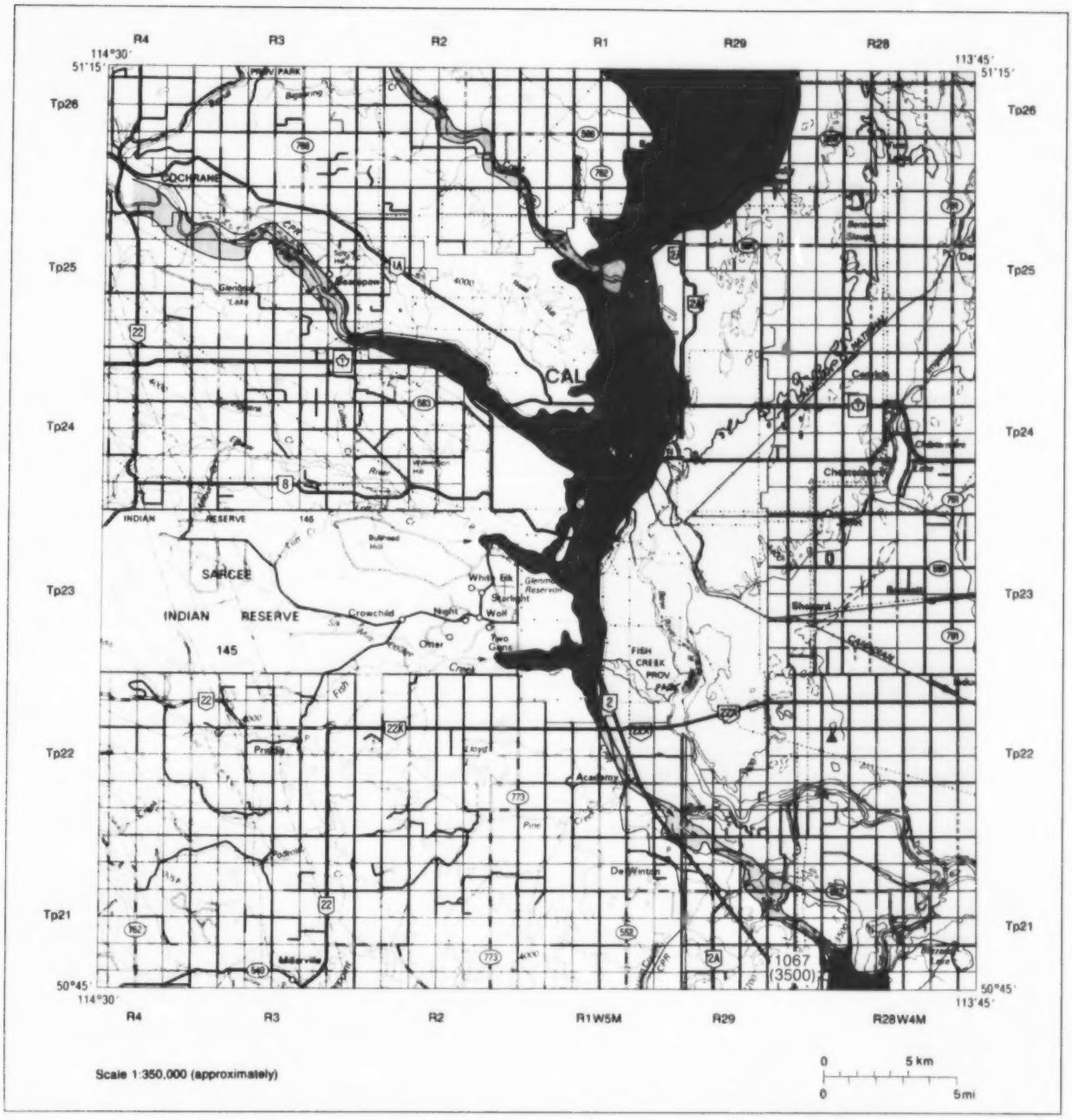
- Low relief stagnation moraine draped over bedrock
- Moulded moraine
- Glacial thrust blocks

Figure 33. Subglacial thrust and streamlined terrain in the Balzac area, north of Calgary

it and reserve definitive interpretation, pending the discovery of corroborative data.

In the absence of any compelling evidence to favor another interpretation, the interpretation of all the surface till units in the Calgary area as late Wisconsinan appears to best fit the regional perspective (Clayton and Moran, 1982).

Dates of 18 300 ± 380 (GSC-2668) and 18 400 ± 1090 (GSC-2670) from a bog west of Turner Valley (Jackson, 1977, 1980, 1983) provide a minimum age for the retreat of the glacier that deposited the lower unit of the Spy Hill Formation from the area southwest of Calgary. These dates provide the only definite chronologic data on which the interpretation of the age of glacial sediment in the Calgary area are based (figure 35). It should be noted that these dates fit equally comfortably into either of the chronological interpretations.



Legend

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- Debris-covered stagnant glacier ice
- Glacier
- 1204 (3950) Level of controlling outlet of lake in metres (feet)

Figure 34. The distribution of glacial ice and related drainage features during the maximum advance of the glacier that deposited the Crossfield Formation in the Calgary area

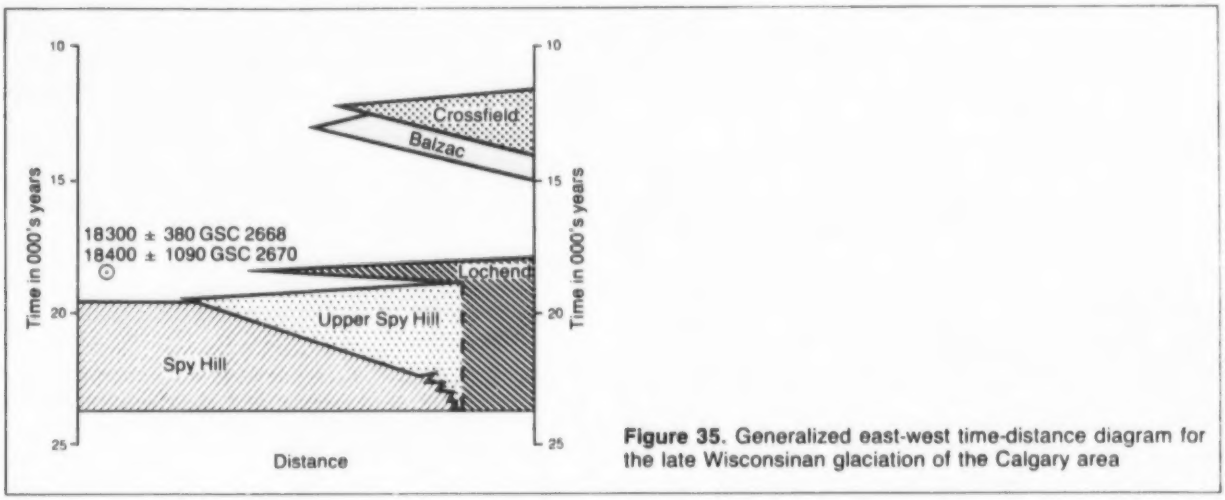

Figure 35. Generalized east-west time-distance diagram for the late Wisconsinan glaciation of the Calgary area

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